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Centre for Sustainable Consumption and Production

Authors: Riina Antikainen[1)], Carl Dalhammar[4)], Mikael Hildén[1)], Jáchym Judl[1)], Tiina Jääskeläinen[1)], Petrus Kautto[1)], Sirkka Koskela[1)], Mika Kuisma[2)], David Lazarevic[1)], Ilmo Mäenpää[1),3)], Jukka-Pekka Ovaska[2)], Philip Peck[4)], Håkan Rodhe[4)], Armi Temmes[2)], Åke Thidell[4)]

[1)]Finnish Environment Institute
[2)]Aalto University
[3)]University of Oulu and [1)]Finnish Environment Institute
[4)]Lund University, The International Institute for Industrial Environmental Economics (IIIEE)

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ABSTRACT

Renewal of forest based manufacturing towards a sustainable circular bioeconomy

Environmental problems, combined with European Union environmental and energy policies shaped to address them, have created pressures for change. Some of these open significant opportunities to renew industries. This report delivers new understanding of the potential of circular economy for sustainable renewal of manufacturing in bio-based industries. With particular focus on novel value chains, it provides novel insights into the role of innovation policies in facilitating the shift towards sustainable, circular bioeconomy in Finland and Sweden. The textile and multi-storey wood construction sectors, and emergent biorefineries are utilised as case studies that deepen understanding of the circular bioeconomy, its opportunities, barriers, and impacts, and the policies that affect its emergence. Recent developments of bioeconomy and circular economy solutions and governance in the Netherlands are also summarised in order to deliver contrasting context to the Nordic focus countries.

In this work, the bioeconomy is conceptualised as an economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources, such as plant and animal biomass. The essence of the circular economy, that is used here, lies in maximisation of added value and in making the best use of any extracted raw material.

This analysis shows that to date discussions and activities related to the promotion of bioeconomy and circular economy have largely been separate efforts, but there are signs that the discussions may converge. It finds that while the form of developments are similar in Finland and in Sweden in the case areas (i.e. textiles, wood construction and biorefineries), there are also clear differences in the strengths of the countries. Evidence is found that such strengths offer potential to develop world leadership in a circular bioeconomy. The report identifies policy recommendations to support renewal of manufacturing in the wood based industries towards a sustainable circular bioeconomy.

Keywords: circular economy, bioeconomy, textiles, timber construction, biorefineries, biomass, natural resources, sustainable use, direction methods, environmental policy, Finland, Sweden, The Netherlands

TIIVISTELMÄ

Puupohjaisen tuotannon uudistuminen kohti kestävää kierto-biotaloutta

Kasvavat ympäristöongelmat ja erityisesti muutokset Euroopan Unionin ympäristö- ja energiapolitiikoissa ovat aiheuttaneet muutospaineita, mutta samalla myös merkittäviä uudistumismahdollisuuksia teollisuudelle. Tässä raportissa kuvataan kiertotalouden tuottamia mahdollisuuksia valmistavan teollisuuden kestävässä uusiutumisessa, keskittyen biopohjaisiin teollisuuden aloihin ja uusiin arvoketjuihin. Lisäksi luodaan kattava kuva innovaatiopolitiikan roolista siirtymisessä kohti kestävää kierto-biotaloutta Suomessa ja Ruotsissa. Tekstiilisektoria, puurakentamista ja biojalostamoja hyödynnettiin esimerkkialoina syventämään ymmärrystä kierto-biotalouden mahdollisuuksista, esteistä, vaikutuksista ja ohjauskeinoista. Raportissa vedetään myös yhteen Alankomaiden viimeaikainen biotalouden ja kiertotalouden kehittyminen.

Biotalous tarkoittaa sellaista taloutta, jossa pääosa materiaalista, kemikaaleista ja energiasta pohjautuvat uusiutuviin biologisiin resursseihin, kuten kasvi- ja eläinbiomassaan. Kiertotalouden ydin on raaka-aineiden arvon maksimoinnissa ja irrotetun raaka-aineen mahdollisimman tehokkaassa käytössä. Toistaiseksi keskustelu ja toimenpiteet liittyen biotalouteen ja kiertotalouteen ovat olleet suhteellisen erillisiä, mutta on havaittavissa, että keskustelut näihin alueisiin liittyen ovat yhdentymässä.

Esimerkkialoilla kehityssuunnat ovat Suomessa ja Ruotsissa samankaltaisia. Maiden vahvuuksissa on myös selviä eroavaisuuksia. Vahvuuksiaan hyödyntämällä ja toisiaan täydentämällä maat voisivat saavuttaa globaalin johtoaseman kiertobiotaloudessa. Raportissa esitetään politiikkasuosituksia puupohjaisen teollisuuden uudistumiseksi kohti kestävää kierto-biotaloutta.

Asiasanat: kiertotalous, biotalous , tekstiilit , puurakentaminen, biojalostamot, biomassa, luonnonvarat , kestävä käyttö, ohjauskeinot, ympäristöpolitiikka, Suomi, Ruotsi, Alankomaat

SAMMANDRAG

Förnyelse av skogsindustrins tillverkning mot en hållbar cirkulär bioekonomi

Olika hållbarhetsutmaningar och EU:s miljö-, energi- och klimatpolitik har inneburit ett ökat förändringstryck för nordisk industri. Samtidigt innebär omställningar möjligheter till industriell förnyelse. Denna rapport bidrar med ny förståelse kring den cirkulära ekonomins potential att stimulera till hållbar omvandling av biobaserad tillverkningsindustri, särskilt med avseende på nya värdekedjor. Den bidrar även med nya perspektiv på innovationspolitikens betydelse för att underlätta övergången mot en hållbar cirkulär bioekonomi i Finland och Sverige.

De tre sektorerna textil, flervåningshus i trä samt bioraffinaderier har studerats för att fördjupa förståelsen för den cirkulära bioekonomins möjligheter, barriärer, och påverkan, liksom behovet av politiska beslut för att driva utvecklingen framåt. Utvecklingen av nya lösningar och politisk styrning av bioekonomi och cirkulär ekonomi i Nederländerna är också sammanfattad i rapporten.

Bioekonomin kan beskrivas som en ekonomi som i huvudsak bygger på att material, kemikalier och ämnen - samt energi - utvinns från förnyelsebara biologiska resurser såsom biomassa från växter eller från djur. I den cirkulär ekonomins kärna ligger att maximera det skapade värdet och att råmaterial används till bästa möjliga användningsområde. Än så länge har emellertid både diskussioner och insatser till stöd för bioekonomi respektive cirkulär ekonomi mestadels varit åtskilda, även om det finns signaler om att de kan konvergera mer framöver.

Utvecklingen är snarlik i Finland och Sverige i de tre fallstudieområdena textiler, träbyggnader och bioraffinaderier. Det förekommer emellertid tydliga skillnader i styrkor länderna emellan, vilka rätt kombinerade kan utvecklas till globalt föredöme inom cirkulär bioekonomi. I rapporten ges rekommendationer för policyåtgärder till stöd för förnyelse av skogsindustrins tillverkning mot en hållbar cirkulär bioekonomi.

Nyckelord: cirkulär ekonomi, bioekonomi, textilier, träbyggande, bioraffinaderier, biomassa, naturresurser, hållbar användning, styrmedel, miljöpolitik, Finland, Sverige, Nederländerna

PREFACE

The comparative advantage of manufacturing in the European Union (EU) is linked to complex and high-quality product segments, and until now EU manufacturing industries have been able to maintain their competitive position by increasing the complexity of their products (EU competitiveness report 2013). Environmental problems, and particularly environmental and energy policies, in the EU have created pressures for change but also significant opportunities to renew industries. In the near future, further improvements in use of renewable resources, resource efficiency, waste reduction and minimisation of intake of natural resources, coupled with new circularity-based business models, are likely to become increasingly important for manufacturing and trade. These developments can become central in enhancing the global competitiveness of European companies, securing material supply security and creating new jobs.

Forest derived biomass has been, and still is, very important for the Finnish and Swedish economies. Importance has been built upon access to, and efficient management of, large forest resources. Forest sector activities are typified by large volume flows and bulk products, with innovation efforts focusing on the increase of raw material yields per unit of productive land, and upon incremental optimisation of bulk production. From an economic point of view such strategies have been successful. Both Finland and Sweden have achieved recognized competitive and comparative advantages in many forest related areas.

In the future, Finland and Sweden have great potential to enhance their global competitiveness and that of European companies, secure their materials supply and create new jobs – however, this will rely to a significant extent upon the successful implementation of recent policies and strategies focused on bioeconomy and circular economy, and how these contribute to a renewal of manufacturing. To create new knowledge about how policies can support the renewal of manufacturing and what demands the renewal puts on policies for a sustainable circular economy, Tekes, the Finnish Funding Agency for Innovation – and Vinnova, Sweden's innovation agency, funded the project RECIBI – *Renewal of manufacturing towards a sustainable circular bioeconomy and implications for innovation policy*. The novel value to be delivered by this project lies in the combination of innovation policy analyses to cross-country comparisons of frontrunner value chains connected to circular bioeconomy, with assessment of both their positive and negative life cycle environmental impacts.

The project was led by the Finnish Environment Institute (SYKE). Other main partners were Aalto University, School of Business and the International Institute for Industrial Environmental Economics (IIIEE) at Lund University. In addition, the Dutch Research Institute for Transitions participated in the project with a minor role in benchmarking the Finnish and Dutch bioeconomies against each other.

This report summarises the main findings, conclusions and recommendations of the project. More RECIBI publications can be found at http://www.syke.fi/projects/recibi.

Riina Antikainen was the lead and coordinating author of the report. Other authors are listed in alphabetical order. The main contributions of the authors are described as follows. Section 1: Riina Antikainen; Section 2: Riina Antikainen, Carl Dalhammar, Mikael Hildén, Petrus Kautto, Mika Kuisma, David Lazarevic, Philip Peck and Armi Temmes; Section 3: David Lazarevic, Mikael Hildén and Armi Temmes; Section 4 (Textile case): Riina Antikainen, Jukka-Pekka Ovaska, Armi Temmes and Åke Thidell; Section 5 (Construction case): Mika Kuisma, David Lazarevic, Håkan Rodhe and Åke Thidell; Section 6 (Biorefinery case): Armi Temmes and Philip Peck: Potential environmental impacts for each case: Riina Antikainen, Jáchym Judl and Sirkka Koskela, with Håkan Rodhe and Åke Thidell for the construction case, while Ilmo Mäenpää performed the macro-economic modelling for the textile scenarios; Relevant policies for each case: Carl Dalhammar, Mikael Hildén, Petrus Kautto, David Lazarevic, Mika Kuisma, Philip Peck, Håkan Rodhe, Armi Temmes and Åke Thidell; Section 7: Riina Antikainen; Sections 8 and 9: Riina Antikainen, Armi Temmes and Mikael Hildén. All authors contributed by commenting and supplementing all parts of the report, except for Tiina Jääskeläinen, who participated in the

initial data collection and performing interviews. David Lazarevic and Philip Peck performed the language check and proof reading.

We wish also to thank Rick Bosman and Jan Rotmans for the Finnish – Dutch benchmarking study and especially Rick Bosman for providing data on the Ducth circular bioeconomy policies and companies. We also thank Mari Heikkinen for help with the translation, and Magda Horvath and Miia-Elina Minkkinen for working as a student and a trainee in the project, respectively. Paula Kivimaa deserves special thanks as co-designer and -initiator of the RECIBI project.

In addition, we wish to thank the funders, interviewees, stakeholder workshop participants and all the other who gave valuable insights for the project.

May 2017

The authors

CONTENTS

1 Introduction

The comparative advantage of manufacturing in the European Union (EU) is linked to complex and high-quality product segments, and the EU manufacturing industries have been able to maintain their competitive position by increasing the complexity of their products (European Commission 2013). Environmental problems, and a number of environmental and energy policies in the EU shaped to combat them, have created pressures for change but also significant opportunities to renew industries. In the near future, further improvements in resource efficiency and waste reduction coupled with new business models are likely to become increasingly important for manufacturing. These developments can become central in enhancing the global competitiveness of European companies, securing their material supply security and creating new jobs.

A number of structural change trends affect Finnish and Swedish forest-based sectors – global demand for printing paper demand is declining, while that for packaging materials, wood products and biofuels is increasing. At the same time, new products, such as novel wood-derived textiles, are being developed for markets. Finland and Sweden have great potential in this area if their recent policies and strategies focused on the emergent bioeconomy can be successfully implemented to renew manufacturing. Yet, many questions remain regarding the kind of manufacturing that will succeed in the future, and the shape and form of institutions and policies that are needed to contribute positively to the required structural change. A bioeconomy, while based on using renewable resources, is not sustainable *per se* as even renewable resources are limited.

The creation of new business forms, new products and renewed manufacturing should also improve the quality of life and increase ecological efficiency. Pursuit of a circular economy requires the closing of material and resource loops. Achievement of such improvements in turn reduces the pressure on virgin natural resources by extending the use time of products, their parts and materials, decreasing the amount of energy use and pollution from the production of new products, and cutting production and post-consumer volumes of waste. The idea of circular economy is gaining ground among various actors in Europe and internationally. Japan for example, has been highlighted as a forerunner in establishing a circular economy, and the circular economy was also identified as a priority area in China's 11th five-year plan for 2006-2010 (Mathews & Tan 2010). In Europe, *Closing the Loop* - An EU action plan for the Circular Economy package was released in December 2015 (European Commission 2015a) – a step that further legitimises the idea within the EU and builds upon several decades of preceding work. The concepts underpinning the circular economy are not new, and ecological economics, environmental economics and industrial ecology are examples that have been highlighted as its significant antecedents.

This project, *Renewal of manufacturing towards a sustainable circular bioeconomy and implications for innovation policy (RECIBI)*, adopts the concept of a circular bioeconomy – referring to the efficiency in and reuse of bio-based resources, and explores the implications of circular bioeconomy for the renewal of manufacturing (Figure 1). Work has been guided by the working assumption that front-runners can benefit from circular economy via pursuit of innovative solutions of product design, and by new resource efficient or frugal business and market models. Additionally, this analysis anticipates that new ways of turning waste, by-products and side-flows into a resource can create new business opportunities.

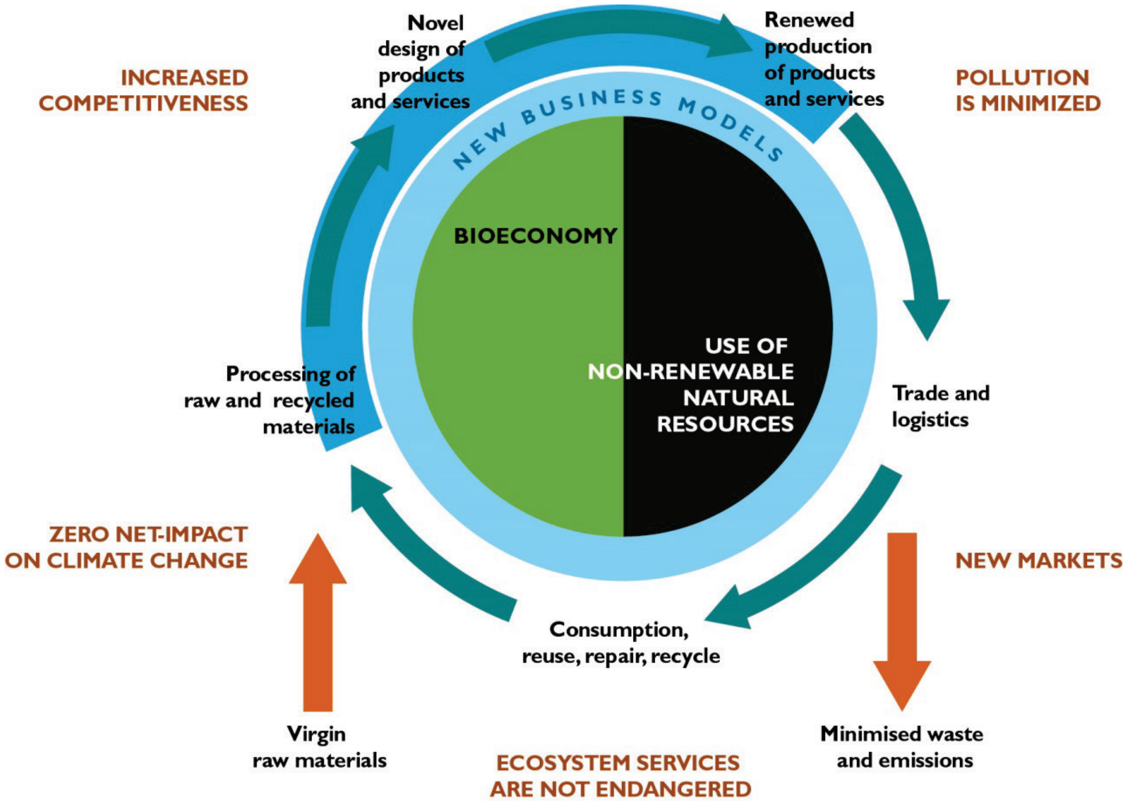

Figure 1. The concept of sustainable circular bioeconomy applied in RECIBI project.

The project aimed to deliver better understanding of the potential of circular economy for sustainable renewal of manufacturing in bio-based industries with particular focus on novel value chains. Further it aimed to provide novel insights into the role of innovation policies in facilitating the shift towards sustainable, circular bioeconomy in Finland and Sweden, and to deliver policy recommendations based on the new insights and lessons.

The project focused on following the tasks:

- delineate the similarities and differences in the renewal of manufacturing in Finland and Sweden with respect to innovative bio-based value chains and materials,
- demonstrate the approaches to analyse and document the sustainability of renewed manufacturing be
- outline how innovative and competitive renewal of manufacturing through novel value chains and business models contribute to the emergence of a circular bioeconomy,
- document the challenges and opportunities that present and expected circular economy policies create for the renewal of manufacturing?
- analyse what challenges does the renewal of manufacturing through circular economy pose for innovation policy and its coherence with other policy domains (e.g. environmental policy, taxation, transport policy) in Finland and Sweden, and
- discuss where should Finnish and Swedish innovation policies – defined broadly as cross-domain policies influencing innovation - focus to effectively contribute to renewal of manufacturing towards circular economy and what lessons can be drawn from the similarities and differences between the two countries and internationally, especially from the Netherlands.

Textile sector, multi-storey wood construction and biorefineries were selected as case sectors to deepen the understanding on the circular bioeconomy opportunities, barriers, impacts and policies. These three sectors were selected because they all can use wood in large extent; represent a significant growth potential both for domestic and international markets, and as they offer potential for renewal of manufacturing activities in both Finland and Sweden. These cases were also found interesting from the project point of view as they were recognised to enfold a wide selection novel business models. Expectations of data availability and access to data were also important selection criteria.

Photo: Laura Rautjoki

2 The bioeconomy and the circular economy

2.1 Wood is the basis for bioeconomy in Finland and Sweden

A bioeconomy is dependent on the sufficient supply of raw material, in this case biomass. The RECIBI project concentrated on the use of wood as a biomass source; this as it is both important for the economy of Nordic countries and because of its relative abundance.

Figure 2 shows the current situation of the wood use in Finland and Sweden. While the total harvest in Sweden is some 25% higher than in Finland, the difference between growth and harvest is in both countries approximately 30 million m^3 annually. There are some differences in the industrial structure between Finland and Sweden. As examples, Finland uses significantly more wood is for energy purposes, while the share of wood used for wood products and the production of dissolving pulp for textile fibres is larger in Sweden.

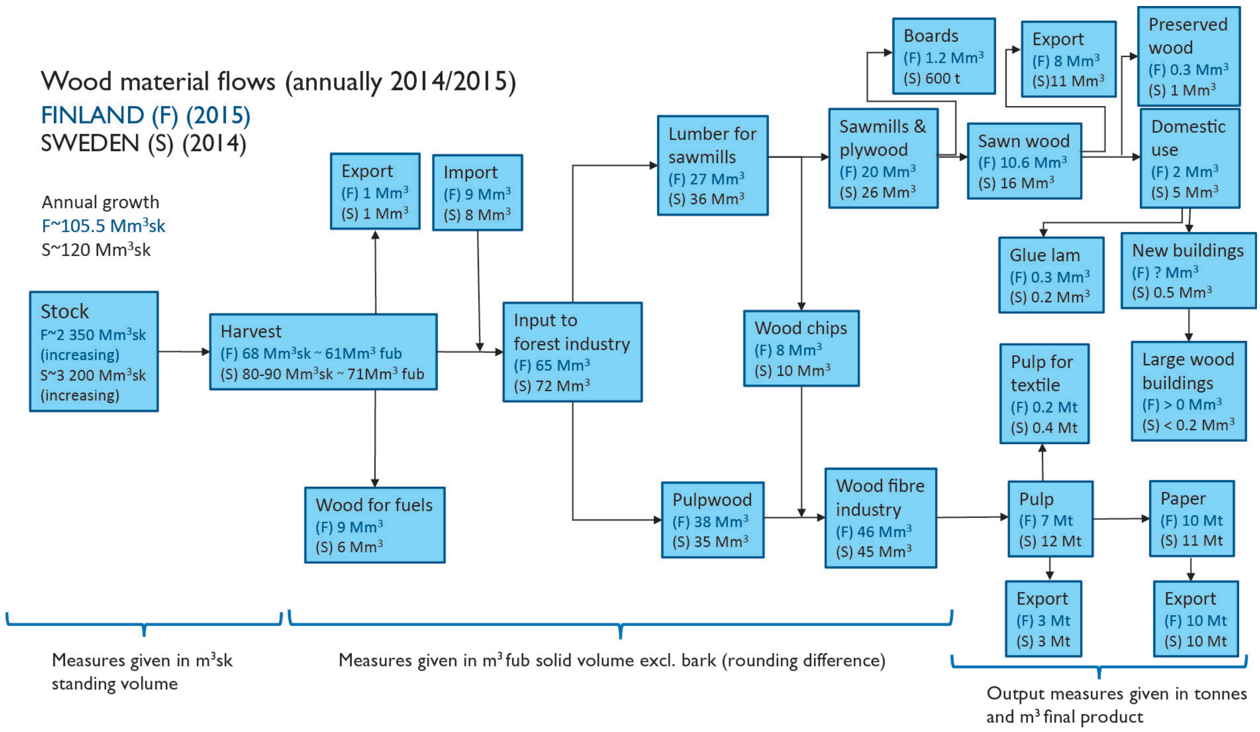

Figure 2. Wood material flows in Finland and Sweden. The standing volume and the raw wood figures to the left are given in solid cubic metres over bark (m^3 sk). The numbers in the middle section of debarked wood entering processes are given as cubic metres under bark (m^3 fub). Note: the volume of pulp production in Finland and Sweden is calculated differently in terms of integrated pulp production, i.e. the statistics of pulp production differ between the two countries. Because of differences in statistics, the Finnish numbers have been recalculated with the standard conversion factor of 0.897. (Finnish Forest Industries, 2016; Finnish Glulam Association, 2016; Finnish Wood Preserving Association, 2016; Natural Resources Institute Finland (Luke), 2016; Stora Enso, 2016, Swedish Forest Agency 2014, Swedish Forest industries Federation 2015)

2.2. Bioeconomy concepts and definitions

The bioeconomy can be conceptualised as an economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources, such as plant and animal biomass (McKormick and Kautto 2013). An economy founded on biomass instead of the fossil hydrocarbons that dominate today will require a massive shift in socio-economic, agricultural, energy and technical systems. The bioeconomy has the potential to meet many of the requirements for sustainability from environmental, social and economic perspectives.

While there are many levels of nuancing with regards to that which social actors 'desire' from the bioeconomy, in practical terms it can be argued that the principal requirement for a bioeconomy is that the products can replace non-renewable, mainly fossil-based chemicals and materials (Table 1).

Table 1. Comparison of the definitions of bioeconomy in Finland and in Sweden (Formas, 2012; MEE, 2014).

	Finland	**Sweden**
Principal requirement	"relies on renewable natural resources" "reduce dependence on fossil natural resources"	"production of biomass to enable increased use within a number of different sectors of society." "reduce…the use of fossil-based raw materials"
Additional sustainability aspects	"prevent biodiversity loss" "in line with the principles of sustainable development" "not wasting natural resources but using and recycling them efficiently."	"reduce climate effects" "reduction in energy consumption" "recovery of nutrients and energy"
Economic aspects	"create new economic growth and jobs"	"optimize the value and contribution of ecosystem services to the economy"

Other parts of the definitions and discussions enfolding the bioeconomy can be seen principally as expressions of efforts to ensure that the shift to renewable resources will not take place "at any cost" – with 'cost' being associated with environmental quality preservation or improvement; climate mitigation; biodiversity preservation/protection and efficient resource use connected to recycling. A bioeconomy is also often expected to contribute increased value from the raw material (Figure 3). These secondary requirements have significant important in this analyse. However, the authors of this report perceive that it remains unclear what degree of proof of sustainability should be required from the actors claiming that they are part of the bioeconomy. This stated, it is held that clear base conditions in the form of broad stakeholder expectations are observable – both in Nordic countries and internationally. These are that energy use, waste and pollution should be much less than for equivalent fossil systems.

A bioeconomy is seen to rely on the development of biotechnologies that "apply science and technology to living organisms, as well as parts, products and models thereof, to alter living and non-living materials for the production of knowledge, goods and services" (OECD 2009). Additionally, intangible values associated with nature; for example, related to 'wellbeing' or utility provided by recreation or relaxation, can also be seen as a component of the bioeconomy.

Bioeconomy definitions also typically contain an element of economic growth and job creation. Indeed, a recent study indicates that the broader EU bioeconomy may already generate EUR 2.1 trillion in annual revenue and 18.3 million jobs (Piotrowski et al. 2016).

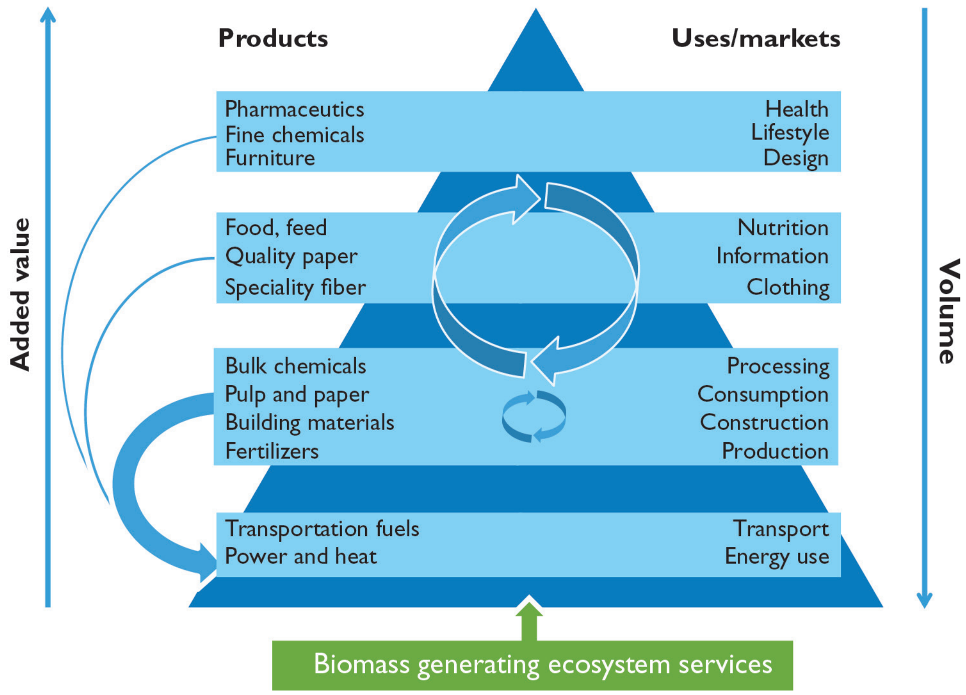

Figure 3. Biomass value pyramid for a circular bioeconomy (modified based on Werkgroep Businessplan Biobased Economy 2011 and Bosman & Rotmans 2014).

2.3 Bioeconomy policies

The European Commission launched its Bioeconomy Strategy in 2012 (European Commission 2012), addressing the production of renewable biological resources and their conversion into vital products and bio-energy. The strategy aims to steer the Europe's bioeconomy in a direction aligned with overall efforts in the EU and to streamline existing policy approaches in this area. The strategy is structured around investments in research, innovation and skills; reinforced policy interaction and stakeholder engagement; and enhancement of markets and competitiveness. Its general objective is to address many challenges facing Europe and the world: these including population growth, depletion of natural resources, and impacts of increasing environmental pressures and climate change. Naturally it is also to ensure that fossil fuels are replaced with sustainable natural alternatives as part of the shift to a post-petroleum society. The Strategy is planned to be reviewed and updated in 2017. An important aspect relevant to this analysis is that the bioeconomy is not viewed as a panacea for all such challenges. Indeed, it has been argued that large-scale shift from fossil raw materials to biomass also has potential to contribute to significant environmental and social problems (see section 6.6).

Many member States, including France, Germany, The Netherlands, Sweden and Finland, have launched national level bioeconomy initiatives. Non-European countries such as the US and China are also investing heavily into bioeconomy efforts (McCormick & Kautto 2013).

2.3.1. Finland

Finland published its bioeconomy strategy in 2014 as a common exercise from three Ministries: Employment and the Economy, Agriculture and Forestry and Environment (MEE 2014). Wood is the most important raw material addressed in the strategy. When defining bioeconomy, Finland apparently places strong emphasis upon environmentally friendly and/or clean technologies and efficient recycling of materials. Bioeconomy definitions in Finland, including that in the Programme of the present government, also emphasize the potential of bioeconomy to create new business and new value chains.

"The Bioeconomy and Clean Solutions" is one of the five strategic priorities of the Government of Juha Sipilä presented in 2015. This document expresses an aim that Finland becomes a forerunner in bioeconomy, circular economy and cleantech by 2025 (Prime Minister's Office 2016). The five key projects within the strategic priority deal with:

- renewable energy;
- increasing wood harvesting and new forest products;
- circular economy and waterways;
- food production; and
- nature policy.

The total funding for the priority area is 300 million euros. The measures most relevant to this study are Measures 2 and 3 in the area of new forest products (Development of new products and acceleration of innovations) and Measure 1 in the area of circular economy (promote recycling). The innovation measures include measures and funding structures to enhance R&D, piloting and experimentation of bioeconomy-related innovations, e.g. funding for Tekes, and sectoral research institutes and pilot centres such as Bioruukki. Recycling measures include regulation prohibiting the dumping of organic waste and exploration of national End-of-Waste legislation.

There is relatively little information about the actual development of recent Finnish bioeconomy.[1] However, according to national statistics, for 2010-2013 the share of bioeconomy of the whole Finnish economy decreased from 19% to 17% and pulp and paper products dominated the Finnish bioeconomy products exports. It seems that so far the bioeconomy has not been able to create new value chains or connections between existing industry clusters (Tahvanainen et al. 2016) and therefore transition towards the bioeconomy seems likely to be a very long-term process.

2.3.2. Sweden

The development of a Swedish Research and Innovation Strategy for a Bio-based Economy has taken place simultaneously to the European developments in the area (Formas 2012), and is recognised as an important enabling condition for the development of bioeconomy in Sweden (Teräs 2015). It highlights four primary areas of action:

- replacement of fossil-based raw materials with bio-based ones;
- smarter products and smarter use of raw materials;
- change in consumption habits and attitudes; and
- prioritisation and choice of measures.

Emphasizing the potential of bioeconomy to create new business and new value chains directs attention to the renewal of manufacturing, not just replacement of feedstocks. Further, Sweden specifically mentions the sustainability of biomass production, reduction of energy consumption and recovery of nutrients. The definition coined in the national research and innovation strategy also highlights the importance of the increased economic value for biobased products, the provision of new by-products from ecosystem services, employment stimulation, and opportunities to improve existing and create new value chains. The central aim of displacing fossil feedstocks while achieving progress towards the bioeconomy also demands consideration and choices in a number of areas; not least in choice of areas to pursue the bioeconomy (and where not to), and how to involve consumers and their behaviour in the process.

As a part of the process to prioritise key areas for Swedish efforts, the Swedish Government commissioned the Agency for Growth Policy Analysis and Statistics Sweden to present metrics describing

[1] Statistics Finland has compiled separate bioeconomy statistics for years 2000-2013 that is partly based on expert estimations. The development of the Finnish bioeconomy based on the statistics is analysed in Antikainen et al. 2016 (Annex B).

the development of the bioeconomy in Sweden. The main project report provides information about export, jobs, and added value in the different Swedish sectors (Tillväxtanalys 2016a). An important conclusion relevant to this RECIBI study is that the quickest way to increase the Swedish bioeconomy is perceived as being to promote the use of wood in buildings – not least as there is a large demand for new house builds in Sweden. As an example of knowledge-capacity building initiative that reflects a related priority for wood science in the country is the creation of the privately and publicly funded Wallenberg Wood Science Centre[2] co-located at Chalmers and at The Royal Institute of Technology KTH.

This stated however, the prioritisation study also indicates that a more long term strategy would be to develop new products for new markets where biobased materials and products are not present today. Among other things, it identifies a need in Sweden to:

- create a more structured analysis of the challenges in the Swedish bioeconomy and areas where government interventions are required;
- prioritise actions and interventions to lower market risks;
- stimulate more collaboration between corporations, universities, research institutes and other relevant actors;
- evaluate existing and develop policies (with public procurement identified as a crucial policy for new market creation); and
- develop new indicators to monitor the expansion of biobased products in new markets.

In another report from the Agency for Growth Policy Analysis, the national systems for promotion of the circular bioeconomy in Finland, Japan and the US were studied so as to place Swedish efforts in an international context (Tillväxtanalys 2016b). The main conclusion of this work was that in the short-to-medium term, as more efforts in this area emerge to inform priorisation, Sweden will need to divide the bioeconomy into various sub-segments (e.g. biofuels, building materials, cellulose) and examine policy needs in each of these segments in more detail.

2.3.3 Comparing Finland and Sweden

Both Finland and Sweden expect to benefit from a bioeconomy and therefore place emphasis on the relevant policies. The Finnish policies, however, are placed at a higher political level, being a strategic priority of the present governmental programme. The Swedish policy is published at the government agency level (e.g. the Energy Agency and other research funding organisations) and is presented as a research and innovation strategy. While bioeconomy strategies are explicit about the need to create value added of the raw materials, many of the actions are related to biofuels and other volume products (e.g. high volume, low value-add).

The Finnish definition of bioeconomy (MEE 2014) connects bioeconomy to circular economy, whereas the Swedish definition of bioeconomy (Formas 2012) emphasizes the connections climate and energy policies (Table 1).

The bioeconomy policies of both Finland and Sweden are closely connected to the renewal of manufacturing and the need to find new solutions to the forest-based industries and another common factor is an emphasis to research and innovation funding.

2.4 Circular economy definitions and concepts

The circular economy operates as a concept that articulates a radically different socio-technological future than the one that exists today (Lazarevic et al. 2016). It has been proposed as a response to the current ‘take-make-dispose’ conventional economic model (EEA 2016, EMF 2013a), and as the goal of

[2] See http://wwsc.se/

the necessary transition from today's current linear economy by its prominent promoters (EMF 2015, 2013a; European Commission 2015a).

The origin of the term 'circular economy' has been ascribed to many authors, and although descriptions include a range of meanings and associations, they generally include representations of cyclical closed-loop systems (Murray et al. 2017). Whilst various attempts have been made to define the circular economy, especially in the grey literature, the oft-quoted definition provided by the Ellen MacArthur Foundation (EMF) prescribes the circular economy as "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals that impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models" (EMF 2013b, p. 7). Definitions of the circular economy also highlight an economy with a strong focus on resources management that goes beyond traditional waste management (Preston 2012) and an economic dimension calling for a rethinking of the purpose of the economy itself (European Commission 2014, TNO, 2013).

A useful lecture-key to understand the organisational modes the circular economy is provided by Stahel and Clift (2015). Drawing on references to capital stock (natural, cultural, human, manufactured and financial) and flows, the authors classify the different emphasis of circular economy interpretations into three categories: loop, lake and performance circular economies. The loop economy focuses on material flows, whereby product materials are not lost from the economy as waste, but recycled for return to the same use. Loops consist of reuse, repair, remanufacturing and material reprocessing (Figure 4). Such loops take place within local economies, regional and global supply chains, and material ownership typically changes with each loop. Examples include global bulk material recycling, 'high quality' material recycling in the EU, or the reuse of products in local economies. Utilising the same loops, the lake economy has a primary focus on optimising and managing the use of stock (not flows) and value preservation without changes to ownership. Examples include the operational leasing of vehicles, construction and medical equipment. The performance economy goes one step further and focuses on optimising the vale obtained from using stock, and is operationalised through business models that sell goods or molecules as 'services'. It is related to the objective of creating "the highest possible use value for the longest possible time while consuming as few material resources and energy as possible" (Stahel 2015, p. 128). The concept highlights the need to shift to service based economies, whereby revenue is derived from providing services as opposed to selling goods (Stahel & Clift 2015). Examples include selling tyre use by the kilometre (e.g., Michelin), power by the hour (e.g., Rolls-Royce turbines) and pay-per-copy office printing (e.g., Xerox).

Concepts underpinning the circular economy have been present since the 1960s, and although the idea has been on the policy agenda since the 1990s (Mont & Heiskanen 2015), only recently has it caught the interest from decision-makers (European Commission 2014, 2011) and the business sector (EMF 2013c). Whilst several concepts have been entangled within the circular economy—such as cradle-to-cradle (Braungart & McDonough 2002), the performance economy (Stahel 2015), biomimicry (Benyus 1997), natural capitalism (Hawken et al. 2013), the blue economy (Pauli 2010), and regenerative design (Lyle 1996)— a recent review (Ghisellini et al. 2016) has shown the ideas entangled within the concept in-the-making have roots in a number of academic disciplines including ecological economics (Boulding 1966, Georgescu-Roegen 1971), environmental economics (Pearce & Turner 1990) and industrial ecology (Frosch & Gallopoulos 1989).

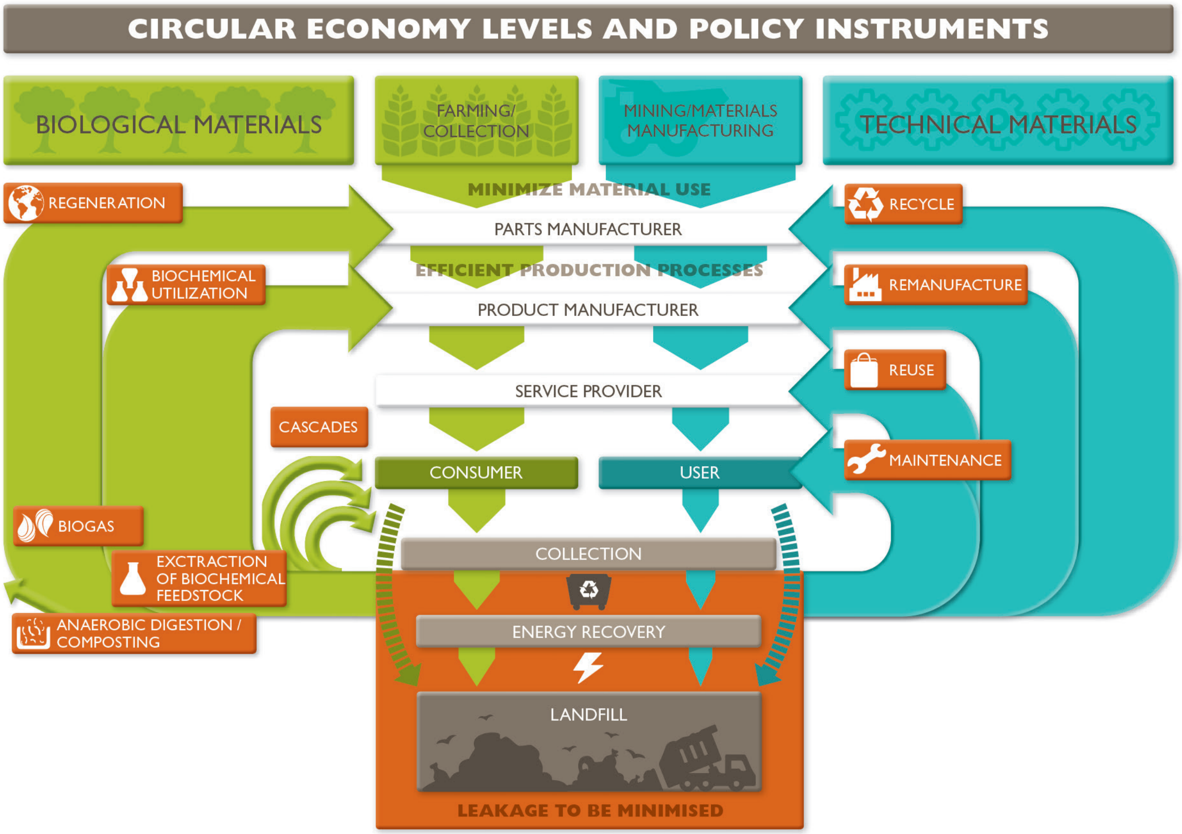

Figure 4. Circular economy levels for biological and technical materials. Source: SYKE (2017), modified from EMF 2013a.

Boulding's (1966) seminal Spaceship Earth essay espoused the notion that a closed earth and a closed sphere of human activity, whose primary concern should be stock maintenance, would necessitate all outputs from consumption to be constantly recycled. This line of thought was continued by Georgescu-Roegen (1971), proposing a fourth law of thermodynamics where matter, like energy, becomes progressively unavailable. Although controversy has surrounded this proposition—the application of the law of entropy to matter (Ayres 1998)—the message that economic systems must consist of the maximum amount of recycling and renewables possible still holds sway (see Daly 1980, Rifkin 1980). The legitimacy of the circular economy is often justified by environmental economics (Gregson et al. 2015), through arguments based in neoclassical economics. Here, the environment provides amenity values, a resource base for the economy, a sink for residual flows and a life support system, and that unpriced or underpriced services should be internalised in the economy (Andersen 2007).

Beyond the conceptual underpinnings of these disciplines, industrial ecology has been suggested to have the greatest practical influence on the development of the circular economy (Andersen 2007, Gregson et al. 2015). Industrial ecology has been defined as "the study of material and energy flows resulting from human activities" providing the basis for "developing approaches to close cycles in such a way that the ecological impact of these activities is minimized" (Boons & Howard-Grenville 2009). The 'oxymoronic term' is rooted in the premise that industrial system can be envisaged as ecosystem (Erkman 1997). Indeed, Frosch and Gallopoulos (1989), two of the intellectual founders of the field, highlight that the metabolism of biological systems predominantly consist of closed loops. The authors draw an analogy between the way biological systems are—"… wastes are in turn food for other organisms" (Frosch & Gallopoulos 1990) in (Jelinski et al. 1992, p. 793) — and the way industrial systems ought to be "material in an ideal industrial eco-system are not depleted any more that those in a biological one are…" (Frosch & Gallopoulos 1989, p. 146).

The primary concerns of industrial ecology are to: improve the metabolic pathways of industrial processes and material use, create closed-loop industrial ecosystems, dematerialise industrial output and systematise patterns of energy use; thus, radically departing from the present day linear economy and its modes of coordination (Ehrenfeld 1997). Strategies for dealing with ecological impact, within industrial ecology, have been categorised in terms of systems boundaries, for instance industrial symbiosis reduces the ecological impact of production by engaging in by-product exchanges in geographically defined clusters, whilst life cycle management coordinates the activities along the value chain (Boons 2013). However, there is little clarity on what levels strategies and actions for the circular economy are targeted.

2.5 Circular economy policies

Policies with references to elements of the circular economy have appeared since the 1990s. They first appeared in broad policy documents such as national programmes for sustainable development, futures studies focusing on the information society, and planning for a European product policy (Heiskanen and Jalas, 2000, p. 14). The ideas developed further and in July 2014, the Barroso led EC published its communication *Towards a circular economy: a zero waste programme for Europe* (European Commission, 2014); a programme outlining steps to move toward a more circular economic model. In December 2014, this package was withdrawn by the new Junker commission, with the promise of a 'more ambitious' package that was published as *Closing the loop - An EU action plan for the Circular Economy* package, released in December 2015 (European Commission, 2015).

The EU actions that are relevant for the renewal of manufacturing in the forest based industries include:

- funding for RD promoting a circular economy;
- development of quality standards for secondary raw materials to increase the confidence of operators in the single market;
- concrete measures to promote re-use and stimulate industrial symbiosis –turning one industry's by-product into another industry's raw material;
- economic incentives for producers to put greener products on the market and support recovery and recycling schemes (e.g. for packaging, batteries, electric and electronic equipment, vehicles).

In addition, actions on water reuse including a legislative proposal on minimum requirements for the reuse of wastewater can also apply to forest based industry and the foreseen strategy on plastics in the circular economy may also open up new opportunities for substitution of plastic with wood-based materials and products.

2.5.1. Finland

Early policy initiatives related to the circular economy date back to 1990s, but it has gained wider acceptance only more recently. In Finland, following the European example, the circular economy concept was brought to the fore in 2014 when intermediary organization Sitra[3] published a report on *The opportunities of a circular economy for Finland* (Arponen et al. 2015). In co-operation with McKinsey management consultancy, Sitra estimated that the circular economy has a value creation potential of at least EUR 1.5–2.5 billion for Finland's national economy by 2030. The report identified five key industries in which the potential could and should be realized: the machinery and equipment, paper, food, con-

[3] Public innovation fund 'aimed at building a successful Finland for tomorrow'.

struction and private consumption centred on a sharing economy. Changes in business models from linear to circular and partnerships with other companies were identified as key means of transition. Apart from public procurement, public policies were not given great attention in the report, and existing regulation was mainly considered as an obstacle for the adoption of the circular operating model.

In spring 2015, the newly appointed Finnish government identified the 'breakthrough of the circular economy' as one of its key projects (Prime Minister's Office 2016, p. 70). The policy focus of the key project is, however, mainly waste oriented. The actions for a more fundamental circular economy have been restricted to commissioned research projects that analyze and assess the policies and potentials of the circular economy, bioeconomy and cleantech in Finland (e.g. Seppälä et al. 2016, ClicInnovation 2017c, Antikainen et al. 2016 and other ongoing studies on e.g., economic instruments supporting the circular economy). In the report, *Circular economy in Finland – operational environment, policy instruments and modelled impacts by 2030* (Seppälä et al. 2016), the economic potential was assessed to be even larger than Sitra has estimated. The study concludes that transition towards the circular economy would benefit both the economy and the environment. In the short-term it was held that focus should be given to replacing harmful material loops with harmless ones. According to Seppälä et al. (2016), existing policy measures mainly support recycling whereas new measures should be designed and implemented to accelerate re-manufacturing and re-use.

The actions towards a more ambitious transition have been documented in the circular economy roadmap *Leading the cycle—Finnish road map to a circular economy 2016–2025* (Sitra 2016). The roadmap is the result of high level collaboration between different ministries, the business sector and other key stakeholders, but it does not have a formal status as a Government Programme. The actions that aim to make Finland a pioneer in circular economy over the next 5 to 10 years thus depend on the private sector and the ability of the roadmap to influence policies.

The roadmap has fully adopted the frame of the Ellen MacArthur Foundation (EMF 2013b). The core idea is to maximize the use of materials by retaining their value in loops for as long as possible, while focusing the foundation for earnings in services and intelligence-based digital solutions. It is suggested that the implementation of the roadmap should proceed through policy measures, key projects and pilots. Selected key projects include:

- regional co-operation bringing sustainable local food to everyday life;
- utilization of public procurement and promotion of nutrient recycling;
- recovery of valuable and rare materials contained in electrical and electronic devices by development of a demonstration plant;
- Finland hosting the World Circular Economy Forum 2017 in Helsinki;
- open data creating low-carbon and smart transport, with development work in the Helsinki metropolitan area;
- forest industry bioproducts moving from labs to trials, testing the replacement of fossil fuels; and
- companies using production and community side streams, that promote the industrial symbiosis concept.

2.5.2 Sweden

Sweden has had a base for developing policies on circular economy in its Environmental Quality Objectives, the National Waste Strategy, and its focus on certain waste streams, as well as other policy initiatives. Among the targets set under the Quality Objective 'A good built environment' are targets related to minimum sorting and biological treatment of food waste, and quantitative targets for construction waste collection and preparation (Swedish EPA 2016). The National Waste Prevention program complements these targets and places focus on four waste streams: food, electronics, textiles, and buildings (Westblom 2015, Naturvårdsverket 2016a).

Recently, there has been an increase in activity related to the circular economy at the national levels. 'A Circular and Biobased Economy' has been launched by the Swedish Government as one of the five Strategic Partnership initiatives (Regeringskansliet 2016a). The aim is to launch innovation platforms – through collaboration between the public sector, the private sector, and academia and research institutes – which can support the transition to a circular economy. The initial phase of partnership initiative and the relevant working groups have noted a number of challenges. These include: that there is a lack of national efforts in the circular economy area; that current laws and policies do not steer developments in the desired direction; that 'circular' and 'biobased' are terms that are quite unknown for the public at large; and that there are limited private investments of relevance (Näringsdepartementet 2016).

The report of the Ministry of Enterprise and Innovation (Näringsdepartementet 2016) suggests that specific policies for the circular economy are still under development in Sweden. Indeed, a number of official inquiries related to the circular economy have been launched. These include an inquiry related to 'Users in the Sharing Economy' (SOU 2017a), and an inquiry on how to best stimulate re-use, repair and the second hand market in Sweden. These focus on the consumer market and products that are of particular interest in relation to resources, the environment and the Swedish environmental quality objectives. The latter inquiry published its final report in March 2017 (SOU 2017b). The main proposals are: 1) the initiation of a Swedish delegation for the Circular Economy, in order to kick-start and steer the process; 2) improve the conditions for carpooling; 3) tax deductions for rental goods, second hand goods and repairs; 4) improve information and infrastructure to enable collection of products that can be re-used and/or remanufactured; 5) proposals to prevent waste in public organisations; 6) change of consumer protection rules to incentivize more durable products; and, 7) measures to improve user confidence and legal security for users engaged in trading and re-use activities. The most important proposal concerns tax deductions for rental goods, second hand goods and repairs. The inquiry does not investigate industrial processes or the bioeconomy.

There is also an ongoing review of Swedish forest legislation that is essential for setting the foundations of forestry practices and may have implications for wood-based materials.[4]

Public procurement has been flagged as a strategic tool to advance towards a circular and biobased economy (Regeringskansliet 2016b). However, there are as yet few national initiatives specifically aimed at promoting the circular economy in procurement. Individual government agencies, regions, and municipalities have progresses and launched initiatives that include the following

- Durable/multiple-use and bio based products in procurement of healthcare products (Dalhammar & Leire 2017) and support for new products through innovative procurement processes (see e.g. Region Skåne 2016).
- Purchasing of remanufactured furniture,[5] and remanufactured IT products.[6]

According to people in the Swedish public sector that we have talked to, there is a large interest in how to develop public procurement to promote CE.

2.5.3 Comparing Finnish and Swedish approaches

There is a general interest in promoting the circular economy in both Finland and Sweden. The EU Action Plan has clearly raised the interest in the circular economy further in both countries. They have a long-standing tradition of exploring and promoting circular economy elements especially in waste related policies. However, the policies that could significantly transform the societies towards circular economies are under development. There are examples of ambitious studies and enquiries in both countries,

[4] Dir. 2015:121, 'Rättslig översyn av skogsvårdslagstiftningen'. The review is however delayed as the original investigator was replaced by the Government.
[5] Interview with Tor Sjödin, Soeco kontorsmöbler, September 2016.
[6] Interview with Erik Pettersson, Inrego, September 2016.

but outside the waste sector there are only limited policy initiatives that appear able to create a significant push towards circular solutions in the forest based industries.

The Finnish policies may emerge out of the extra-governmental roadmap and the Swedish ones may be linked to the Environmental Quality Objectives and the innovation platforms. In practice the routes differ little. As an example, both countries see public procurement as one of the means to advance circularity, but the first efforts to develop a 'circularity practice' are only emerging. They have not yet contributed to any rapidly expanding new business models for the forest based industries or a tangible evidence of the renewal of manufacturing. Given that many of the private sector firms that could make the circular economy real operate in both countries, there are strong arguments for harmonizing policy developments. An area where this may be pursued could be through joint studies or policy experiments that test and evaluate innovative policies.

2.6 Circular bioeconomy

In the frame of the Ellen MacArthur Foundation (EMF 2013b) the biobased economy is seen as distinct from the technical economy that builds on mining of metals and other 'technical nutrients' and manufacturing (see also Figure 4). For countries like Finland and Sweden with large wood based industries this distinction is misleading and can lead to missed opportunities. This happens because many actors take circularity for granted in the bioeconomy, but only in a classical sense of recycling fibres or organic matter. For example, a recent report on the circular bioeconomy in Scandinavia and European Bioeconomy by Reime et al. (2016) does not make a single reference to refurbishing, remanufacturing, repair or recycling of actual products that are essential elements in circular economy. The report sees recycling mainly as an improvement of existing waste based recycling and more efficient recycling loops in the industrial processes.

While traditional recycling is important for resource efficiency, these developments miss an important part of the circular economy concept, and consequently increase the risk of missing opportunities for new business models and further strengthening of the resource economy. The cases presented in the *Nordic Bioeconomy 25* cases for sustainable change (Nordic Council of Ministers 2017) also largely neglect the wider circularity aspects of the bioeconomy, although the selection criteria for the cases indicate that they could be addressed within them.

In the RECIBI project, particular attention has therefore been placed on 'the renewal of manufacturing of forest based industries' so that several circularity features can be strengthened. This has required that attention be paid to emerging and potential forest based loops based on reuse, repair and remanufacturing – in addition to, and beyond material reprocessing. This focus stresses the importance of product design, business models and the preconditions for loops to emerge and be maintained.

3 Theoretical frameworks applied

To explore and understand innovation processes and policies that can support the sustainable renewal of manufacturing in bio-based industries, RECIBI has applied theories of socio-technical transitions (Markard et al. 2012), including the multi-level perspective of system innovation (MLP) (Geels 2004) and technological innovation systems (TIS) (Bergek et al. 2008). Whilst transition concepts and approaches have undergone development and refinement since the late 1990s (Kemp et al. 1998), interest in the discourse of transitions and system innovation can now be seen in high-level international policy bodies, such as the European Commission (2015b), OECD (2015) and UNEP (2011). These concepts have only recently been applied to the green economy (e.g., Gibbs and O'Neill 2014) and the circular economy (e.g., Jurgilevich et al. 2016; Jackson et al. 2014).

Transitions have been defined as the shift from one socio-technical system that provides a societal function (i.e. mobility, energy) to another. Such shifts involve radical, path-breaking innovations; the result of co-evolutionary interactions between socio-technical systems (the tangible artefacts and infrastructure needed to fulfil societal functions), institutions (stable formal and informal rules that guide and coordinate action) and networks of actors and social groups (that maintain socio-technical systems and institutional structures) (Geels and Kemp 2007). Importantly, transitions not only refer to technological change, but require changes in multi dimensions, such as: technologies and their cultural meaning, infrastructure, industry structures, markets, user practices, policies and techno-scientific knowledge (Geels 2002). This approach allows for an understanding of the dynamics of how radical niche innovations influence or even change mainstream technological trajectories.

A common approach to frame and understand change in socio-technical systems is the niche based MLP. The MLP suggests that transitions occur through the interaction of processes between three different levels: the landscape, regime and niche. The landscape refers to the exogenous context that is beyond the influence of actors. It is a heterogeneous melange of elements that include: unchanging or very slowly changing factors (e.g., spatial structures, the climate, etc.); long-term changes in macro-level societal and economic trends, societal values or political ideologies; and specific shocks (e.g., crises of fuel security or political instability). Regimes, are influenced by the landscape, and consist of the prevailing *institutions* that are actively shared by networks of *actors* that result in conventional trajectories of *technological* development. Niches are spaces where novel innovations (technologies and practices) are nurtured and may eventually grow to challenge the dominant regime. Innovations develop in small social networks and as they are protected from normal market selection they act as incubation spaces for radical innovations (Geels 2004). At the general level, the MLP suggests that transitions occur through the interaction between processes at these three levels: (a) niche-innovations build up internal momentum, (b) changes at the landscape level create pressure on the regime, and (c) destabilisation of the regime creates a window of opportunity for niche innovations (Geels and Schot 2007). Niche innovations have been found to develop through three niche-internal processes, namely articulation of expectations, building of networks and learning (Schot & Geels 2008, Raven et al. 2010). In successful niches the expectations have been found to become increasingly specific and convergent, the networks become broader and learning includes questioning of basic assumptions of the regime.

In this report, the MLP is used as a framing tool to aid understanding of the challenges and opportunities to the renewal of manufacturing posed by the move toward a more circular and bio-based economy. As our cases mostly describe developing niches, the niche processes are used to observe the development. Table 2 provides a brief description of the cases and the specific focus, the regime characteristics and the niches have been examined in each case.

Table 2. RECIBI cases and corresponding niches and regime characteristics.

Case and focus	**Current regime characteristics**	**Niches**
Textiles: clothing	Cotton and synthetics as raw materials Low price and short life of clothing Large proportion discarded as waste	Wood-based raw materials Refurbishing business models Sharing business models Collection and recycling initiatives
Construction: multi-storey buildings for housing or offices	Concrete and steel as raw materials Renovations and reuse cumbersome (e.g. plumbing) Elements and on-site construction	Wood as raw material Low-energy housing (nZEB) Flexibility of buildings during lifetime Modular construction
Biorefineries: the range of products being developed	Traditional pulping or fossil fuels	High-value pharmaceutical or food applications Specialty chemical applications Textile fibre applications.

The TIS framework is widely used to study the dynamics of technological innovations, especially in their early stages of development (Markard et al. 2015). A TIS has been defined as “a set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilisation of variants of a new technology and/or a new product” (Markard and Truffer 2008, 611). Jacobsson and Bergek (2004) distinguish between the formative and growth phases of a TIS, which differ in terms of the character of technical change, the patterns of entry and exit, and the rate of market growth. The TIS approach adopts a systemic perspective to analyse the structure of an innovation system, the links between different actors and social networks and the institutional contexts around a specific technology. Authors suggest that a well-functioning TIS is a requirement for the development and diffusion of a technology (Bergek et al. 2008; Hekkert and Negro 2009). Hence, analysis often focuses on assessing the performance of the TIS by analysing how well certain functions, shown to be important for the development of new technologies, are fulfilled. Bergek et al. (2008) propose an often used typology, suggesting the following seven system functions: knowledge development and diffusion; influence on the direction of search; entrepreneurial experimentation; market formation; legitimation; resource mobilisation; and development of positive externalities.

Recently, Kivimaa and Kern (2016) have extended the TIS functions approach developing an analytical framework that analyses the creative destruction potential of policy mixes. TIS functions, are based on Bergek et al. (2008), with the replacement of removal *positive externalities* by *price-performance improvements*. These TIS functions are used as a basis for the ‘creative’ innovation inducing potential of policies. The destructive and regime destabilising potential of policies are captured by four “regime destabilising” functions: control policies; significant change in regime rules; reduced support for dominant regime technologies; and changes in social networks, replacement of key actors (Kivimaa and Kern 2016). These functions are explained in Table 3. This report used the analytical framework outlined in Kivimaa and Kern (2016) to analyse the policy landscape around the bio-textile, multi-storey wooden construction and bio-refinery innovation systems. Recommendations are then made to inform policy-making on how to support the development of these emerging innovation systems.

Table 3. Analytical framework (adapted from Kivimaa and Kern, 2016).

Potential innovation/system influence of policy instrument	Examples of relevant exemplifying phenomena	Description of policy instruments
Creative (niche support)		
Knowledge creation, development and diffusion (C1)	Strengthening knowledge base and how that knowledge is developed, combined and diffused R&D and network support Includes different types of knowledge, e.g. scientific, technological, production, market, logistics and design, and sources of knowledge	R&D funding schemes, innovation platforms and other policies aiming to increase knowledge creation and diffusion through networks; subsidies for demonstrations; educational policies, training schemes, coordination of intellectual property rights, reference guidelines for best available technology.
Establishing market niches/market formation (C2)	Strengthening market formation by creating new customer demand, e.g. through institutional change Comprises niche markets, bridging markets and mass markets. Can be created through policy action but may pre-exist in form of green consumers	Regulation, tax exemptions, market-based policy instruments such as certificate trading, feed-in tariffs, public procurement, deployment subsidies, labelling.
Price-performance improvements (C3)	Policy support for achieving price-performance improvements to make niches competitive with incumbent technologies	Deployment and demonstration subsidies enabling learning-by-doing; R&D support (cost reductions through learning).
Entrepreneurial experimentation (C4)	Involves the reduction of uncertainties as a consequence of testing of new technologies, applications and markets Enabling piloting, the creation of new opportunities and learning Support for entrepreneurship, e.g. through innovative policy designs, that address the formation of new actors and networks	Policies stimulating entrepreneurship and diversification of existing firms, advice systems for SMEs, incubators, low-interest company loans, venture capital; relaxed regulatory conditions for experimenting.
Resource mobilisation (C5)	Mobilisation of human and financial capital, and complementary assets such as network infrastructure	Financial: R&D funding, deployment subsidies, low-interest loans, venture capital. Human: educational policies, labour-market policies, secondment of expertise.
Support from powerful groups/legitimation (C6)	Legitimacy, i.e. social acceptance and compliance with relevant institutions, needed for many other functions to work. Legitimacy influences expectations among managers Shared positive expectations legitimate the continuation of protecting and nurturing a niche	Innovation platforms, foresight exercises, public procurement and labelling to create legitimacy for new technologies, practices and visions.
Influence on the direction of search (C7)	Incentives and/or pressures for organisations to enter into the technological field Influenced by visions and expectations articulated by companies and in policies, by landscape changes, and by legitimisation. Conflicting policy goals and instruments are likely to diminish this influence.	Goals set and framing in strategies, targeted R&D funding schemes, regulations, tax incentives, foresight exercises, voluntary agreements.

Destruction (regime destabilisation)		
Control policies (D1)	Required to put pressure on the regime. Internalising environmental externalities to create an 'extended level playing field' for niches and incumbent technologies to compete on fair terms Crucial for transitions	Policies, such as taxes, import restrictions, and regulations. Control policies, for example, carbon trading, pollution taxes or road pricing to put economic pressure on current regimes. Banning certain technologies is the strongest form of regulatory pressure (e.g. phase out of fluorescent light bulbs).
Significant changes in regime rules (D2)	Reconfiguration in institutional rules favourable to the status quo/path dependent evolution of the regime Radical policy reforms, where policies substantially change economic frame conditions	Policies constituting, for example, structural reforms in legislation or significant new overarching laws. Historic examples of major rule changes include the privatisation and liberalisation of electricity markets in the 1990s.
Reduced support for dominant regime technologies (D3)	Withdrawing support for incumbent technologies that are institutionalised and make it difficult for innovations to break through Changed balance between a process or a product and existing resources	Withdrawing support for selected technologies (e.g. cutting R&D funding, removing subsidies for fossil fuel production or removing tax deductions for private motor transport).
Changes in social networks, replacement of key actors (D4)	Replacement of incumbents by new actors Replacing existing skills and knowledge (of actors) with new ones Deliberately breaking up established actor-network structures or developing different fora to bypass traditional policy networks	Balancing involvement of incumbents for example in policy advisory councils with niche actors; formation of new organisations or networks to take on tasks linked to system change.

4 Circular bioeconomy in the textile sector

The textile sector provides multiple opportunities for Finnish and Swedish manufacturers and businesses. Novel wood based textiles, development of circular textile business models, and design for prolonged product lifetime plus recyclability all offer potential to improve the sustainability of the textile sector. For the development of the sector towards the circular bioeconomy, it is necessary for the resurgent (renewed) cellulose fibre production for textiles to move from laboratory scale experiments to pilot scale production of new wood cellulose fibres. Similarly, it is necessary to scale up and pilot the development and introduction of collection and sorting schemes and to stimulate and enhance markets for recovered textile fibres. A crucial step is also to connect the development of novel wood based textiles and reuse and recycling of textiles, that currently are mostly separate approaches.

4.1 Aim and methods

A case addressing the textile sector was selected for the RECIBI project. This includes new kinds of textile fibres derived from wood as it is seen as one potential direction for renewing the manufacturing and development of the bioeconomy that is particularly relevant to Finland and Sweden. Production of textiles can improve the value added of the biomass by providing products that are relatively high in the value pyramid. Moreover, the case also provides interesting new developments in the field of circular economy in the textile sector, including initiatives of recovery and recycling, the utilisation of excess capacity in pulp mills and sharing platforms, extending life time, and resource efficiency. Development of novel wood based textiles and improvement of the circular aspects throughout the value chain could provide a more long-term sustainable solution than the current situation in the textile industry – with the current system built predominantly upon cotton, polyester and other synthetic fibres and traditional viscose mainly in a linear flow. In this case, we use the term fibre to describe the raw materials, being processed into yarn and fabrics for various purposes such as home textiles and clothes (sometimes the word apparel is used as synonym). The focus was thus in consumer and home textiles while technical and industrial textiles are largely omitted from the case, due to the often-small quantities and highly specified quality requirements making them unsuited for a general study like this.

Within the case, we first discuss the general characteristics of the textile sector globally, and then focus in to the Finnish and Swedish current situation and trends. Then, we elaborate on the background and possible development of wood-based textiles in Finland and Sweden. In this discussion, the term wood-based textiles include all kinds of textile fibres derived from wood, which from commercial perspective are viscose and viscose-like materials. The materials are sometimes labelled as ‘regenerated’ or ‘man-made’ cellulosic fibres to contrast conventional synthetic fibres such as polyester. In this study, we also distinguish between traditional/conventional and novel viscose. In this report reference to traditional/conventional viscose production is by intent associated with poor work (occupational health and safety) conditions and severe environmental problems that can be observed in production in China for example (Chou et al. 2004; Pang 2002). The development of novel viscose implies improved occupational health and environmental conditions by either production of new fibre qualities in novel processes or similar fibres with more environmentally sound processes. The Lyocel® and Tencel® fibres are examples of novel viscose. The rationale for using the novel viscose concept in this analysis is the notion that a future wood-based Finish and Swedish textile industry will build further opportunities to produce viscose-like fibres but that they will be produced in an environmentally conscious way.

This discussion also addresses the potential development of the textile industry towards a circular bioeconomy, as well as environmental aspects from a lifecycle perspective. Using macroeconomic scenario tools, we exemplify a number of potential economic and environmental impacts of selected textile production scenarios. Finally, we consider the relevant policies that prevent and promote the development of textile sector towards circular bioeconomy.

This case has been produced as a desktop study supported by interviews with experts and practitioners in different positions in the textile sector (Table 4). In addition, two stakeholder discussions were organized and the ideas presented by these actors are included in the report. The macroeconomic potential of textile remanufacturing was performed with the ENVIMATscen model, which is an environmentally extended long-term simulation model (see section 4.5.2).

Table 4. Interviews for the textile sector case in Finland and in Sweden. More details in Appendix 1.

Finland	Sweden
4 Representatives of research	5 Representatives of research
9 Representatives of companies	13 Representatives of companies
2 Representatives of waste management actors	2 Representatives of waste management actors

4.2. General characteristics of the textile sector

The textile sector is one of the largest industries in the world and there is a rapidly growing global demand for textile fibres. In 2015, global production of textile fibres was circa 90 Million tonnes, more than double the production volumes of 1990 (CIRCFS 2017). The supply chains related to textile production are often multinational, long and complex, while the use time of textiles is often short due to cheaper clothing and fast fashion cycles.

In addition to a significant increase in global textile fibres demand, the sector is characterised by a substantial demand of synthetic fibres, mainly polyester, while the demand for cotton has stagnated since mid-2000s (Textile World 2015); Figure 5. In mid-90s, about 50% of world-wide textile fibres production was natural and 50% synthetic, while in 2015, cotton accounted for 23%, synthetic fibres 69%, and man-made cellulosic fibres (MMCF) for only 7% of the world textile fibre production (CIRFS 2017a). The forecast to 2030 predicts that the global demand for textile fibres will more than double from the current level (Textile World 2015). The increase is expected to be filled through a drastic increase for polyester fibres, and a steady but lesser increase for cellulosic fibres. Cotton production is expected to be stable at current level.

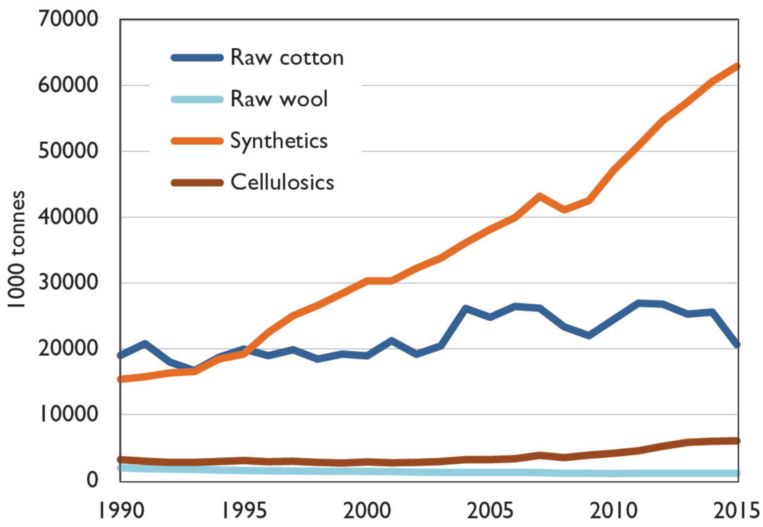

Figure 5. Global fibre production between 1990 and 2015 (CIRFS 2017a).

Cotton is cultivated in temperate, subtropical and tropical regions of the world but the main farming areas are in the Southern states of the US and in the mild regions of Asia. Global cotton production increased until mid-2010s, after which the annual production has remained approximately at the same level of about 25 million tons (FAO 2017).

As indicated, currently wood-based textile fibres represent about 7% of all textile fibres (Figure 5), but demand is growing. Reasons for this include factors such as the limited growth potential of cotton, but are also affected by the pursuit of new markets by the pulp and paper industry in response to the declining global demand for printing paper. The production of viscose fibres has almost tripled between 1990 and 2010, reaching around 3 million tonnes (YNFX 2013). In 2015, the production of viscose reached almost 6 million tonnes and is expected to further increase (CIRFS 2017a). However, the volumes of viscose fibre production are still far below that of cotton fibre. China is the dominant producer of man-made cellulosic fibres with approximately 60% of world production. Most of the new production capacity is also located in China followed by India and Indonesia. However, there is still a significant production of manmade cellulosic fibres in Europe. The production in Western Europe is rather stable at a level of about 550 000 tonnes per year, representing less than 10% of the global production (CIRFS 2017b). The main companies producing viscose are Lenzing and Birla (RISI 2014, Bywater 2011).

Asian countries, e.g. China, India, Bangladesh, Vietnam, Burma, produce most of the clothes that are sold on the world market. A sharp decrease in imports of cotton into the EU-28 countries to about one fifth since mid-1990s (OECD-FAO 2016) reflects the declining production by the whole European textile industry.

In 2012, approximately half of the global consumption of clothes took place in Europe and the US. As growth in consumption is expected to be much stronger in emerging economies, Europe and the US are expected to comprise only approximately one third of the global consumption of clothes in 2025 (Statista 2017).

4.3 Textile sector in Finland and Sweden

Finland and Sweden are both industrialized countries with high consumption of textiles and clothes, but neither of them are significant producers of textiles despite successful fashion industries. In both countries the current general trend is similar to other European textile production - shutting down local production, including operations such as yarn spinning, knitting, and weaving. At the same time, consumption of clothes is growing, thus increasing the need of their imports. For example, in Finland, import of clothes has increased approximately five-fold between the years 1985 and 2015 (STJM 2017).

Imports occur mainly from Asian countries, e.g. in Finland more than 30% of textiles and clothes import came from China (STJM 2017). The Swedish fashion industry is dominated by a few brands that perform design, development, and logistics in Sweden but with their production in other countries, mainly in Asia. The current domestic production of clothes and home textiles is rather small: there are a few linen weavers and producers of knitwear, some producers of high-quality clothes, and a number of subcontracting companies.[7] In addition, there are a small number of producers of technical textiles.

The growing textile and clothing consumption is also driven by a rapid increase in fast fashion and short-term use of clothes with decreased quality. Another notable trend is introduction of technical and functional textiles including electronics and substances for a given performance such as anti-bacterial or water-proofing treatments, as well as having several layers of different materials in fabrics, clothes and textiles. The Swedish household consumption of footwear and clothes (i.e. not including home textiles)

[7] In their study (Mouwitz and Svengren Holm 2013) found 23 textile subcontracting businesses in Sweden for clothes or fashion. The study excluded manufacturers solely producing for their own brands, producers of technical or interior textiles. The largest had 80 employees.

increased by 50% from year 2000 to 2010. In Finland, the average consumption of textile products was 13.2 kg/capita in 2012 (Dalhbo et al. 2017), corresponding to the Swedish consumption of clothes and home textiles which in 2013 was about 13 kg per person and is expected to reach about 14 kg/capita a year in 2020 (Elander et al. 2014).

Currently, recycling and reuse play minor roles in both countries textile flows (Figure 6) and the patterns are very similar. In 2012, in Finland, 20% of the discarded textiles were separately collected for reuse by charity organizations and 80% of textiles from consumers and commercial laundries ended up in municipal solid waste (MSW) where their energy is recovered (Dahlbo et al. 2017). From the separately collected textiles, the majority were exported for reuse and the rest were rejected into municipal solid waste (MSW) stream. The amount of textile waste that was recycled corresponded to less than 2% of the annual total annual domestic use of textile products in 2012. The figures for Sweden are similar: after use, about 80% of textiles end up in waste sector where it is incinerated for energy recovery. In 2013, each Swede sent about 8 kg of textiles as household waste and delivered about 2.4 kg for reuse and recycling, mainly via charity collection systems. Out of the circa 20% of the annual consumption that is collected for charity, about 25% goes back for reuse or resale in Sweden while the majority is exported.

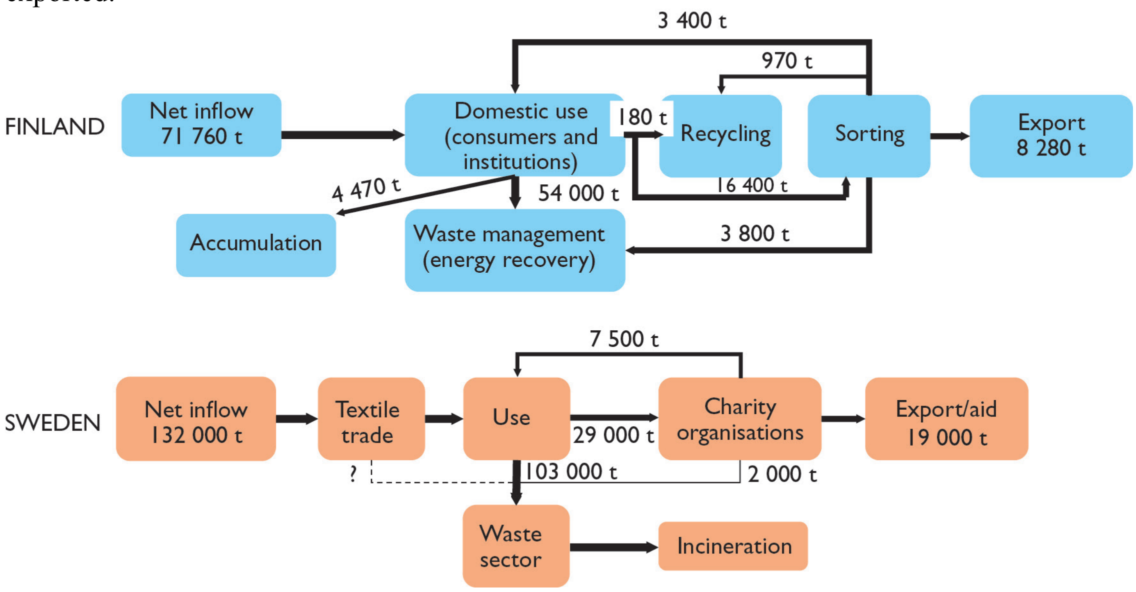

Figure 6. Textile flows in Finland and Sweden (modified based on Dahlbo et al. 2017 and Palm et al. 2014).

Recent developments in the Finnish and Swedish textile sectors show developments in two distinct areas. Firstly, there is growing interest in cellulose-based fibres including traditional viscose, which has increased the production of dissolving pulp both in Finland and in Sweden. Methods for producing dissolving pulp in the kraft process have been further developed. As the traditional viscose process is not very attractive because of its environmental impacts novel processes have been developed with the Finnish Ioncell F as the most advanced process. All these processes still need technical development before entering commercial scale. As the share of cellulose-based fibres of the whole textile fibre market is at the moment small, even small changes in market share offer significant growth possibilities for cellulose-based fibres.

As the disposal of textile waste in landfills is no longer possible in Finland and in Sweden as a result of EU waste regulations, various activities on textile recycling are being initiated in addition to the long-established recovery and reuse schemes that are mostly run by charities. Consumers can now recycle garments, shoes, home textiles through different channels organised by different actors.

The real challenge for circular economy of textiles is the recovery and recycling of end-of-life textiles. In Finland approximately three quarters of all textiles used (both clothing and industrial textiles) end up in waste incineration. Bottle-necks occur in a number of areas: recovery systems are insufficient and cumbersome for users, sorting is inadequate, and there is not sufficient market for the recovered textiles. Currently, collected old textiles are most commonly recovered for valorisation in low value-added applications such as insulation or incineration, i.e. they are downcycled. A few municipalities in Sweden organise their own collection of "miscellaneous textiles – not sellable" where citizens can dispose used textiles that they consider are not suitable for the charity organisations. These municipalities send the items collected to large commercial sorting plants in Germany, The Netherlands, Poland, and the Baltic states.

4.3.1 Wood based textiles in Finland and Sweden

Wood is a natural raw material for a Finnish and Swedish bioeconomy-based textile sector. Wood is processed into dissolving pulp, a speciality pulp that is a purer form of cellulose than paper pulp. The dissolving pulp is further processed into various kinds of textile fibres, spun to yarn and weaved to fabrics. The best known cellulosic textile fibre is viscose (also called rayon).

Viscose fibre production has been known for over a century. The traditional production method uses hazardous process chemicals such as carbon disulphide (CS_2). As a result of the challenges with such substances, there have been various attempts to develop novel processes with less environmental impact and different properties of the final product. The first novel viscose process is the one for making Lyocell fibres that have been known for more than two decades (Woodings, 1995). The best known brand is Tencel that is produced by the Lenzing Group.

In Finland, traditional viscose was produced until 2008, when Kuitu Finland went bankrupt. After that Avilon Oy attempted to restart the production at the existing factory but it failed. In Sweden, Svenskt Konstsilke, a firm that commenced operations in 1918 as the first producer of viscose, yarn and fabrics, liquidated its production in 1967 and turned to other business segments. The last viscose plant for textile fibres in Sweden, Svenska Rayon, closed down in 2004 after years of decline. Since then, there is no commercial production of viscose fibres for clothes and home textile in either Finland or Sweden. However, Freudenberg has a viscose production for non-woven sponge cloths (Wettex) in Norrköping. The company is using dissolving pulp from Swedish producers.

Recently, Finnish and Swedish companies have shown a growing interest in the production of dissolving pulp. The interest is both related to the growing demand of the wood-based textile fibres and to the reduction in the demand for paper pulp, driving companies to search for new business. Traditionally, viscose has been produced from sulphite pulp. In Finland sulphite pulp production ended in the 1990's but in Sweden especially Domsjö Fabriker (part of Aditya Birla) continued production and developed into a biorefinery producing, among other things, dissolving pulp. Recently the production of dissolving pulp from kraft pulp has also become feasible. The main Swedish example is the Södra cell Mörrum mill and in Finland the Stora Enso Enocell mill which both have added production lines for dissolving pulp. In Finland, the production capacity of dissolving pulp in 2012 was about 150 000 t per year (RISI 2014) and in Sweden about 380 000 t per year (Peter Axegård, personal communication). In order of magnitude, this is about one tenth of the world production of dissolving pulp, but it remains only in the order of minor percentage points of the Finnish and Swedish pulp production. The production is aimed for export markets except for the small fraction used by the Freudenberg plant.

As of the first quarter of 2017, this research has not found any actor providing substantiated plans for production of man-made cellulosic fibres in Finland or Sweden but both StoraEnso and Metsä Fibre actively participate in R&D initiatives in the area. Both in Finland and Sweden there are several promising R&D projects that aim for environmentally preferable fibre production from both wood (dissolving pulp) and textile waste. There are also activities targeting subsequent downstream operations (mainly

Aalto University and VTT in Finland, and Swerea, Innventia, Chalmers and KTH in Sweden). Research on the Ioncell F process developed in Finland by Aalto University has shown that high quality fibres can be produced with novel technologies, but there are still major hurdles in the economics of the process related to (among other things) solvent recovery. Even if the results are very promising, informants indicate that there is still is a long way to a commercial process.

In addition to moving towards increased production and consumption of sustainable wood-based textiles, the circular bioeconomy needs to amend circular aspects of the whole value chain. Material in section 4.4 elaborates on this theme, and provides examples of recent activities and development of novel business models than can enhance transition of the textile sector towards a circular economy.

4.4. Circular bioeconomy approaches in the textile sector in Finland and Sweden

The volumes of textile going to waste, and mainly incineration, in both Finland and Sweden are high because the traditional flows to reuse and recycling are low (see Figure 6) for flows in Finland and in Sweden). Legislation banned disposal of textile waste to landfills, in Sweden over ten years ago and in Finland from the beginning of 2016. In both countries, there are numerous activities and experiments seeking to separate textiles before they reach the waste streams through various collection schemes. In addition, initiatives for using collected textiles in various applications have emerged, but both the collection schemes and circular business models are still small in scale. The next section describes actors, business models and material flow cycles identified during the study.

4.4.1 Circular business models in the textile sector

As an analytical frame we use the model in Figure 7, modified from the circular economy model of the Ellen MacArthur Foundation (EMF 2013b). The model includes three elements: roles within a value chain, material flows (arrows) between the roles - especially the different cycles of reuse and recycling, and circular economy business models (combined from Accenture (2014) and Sitra (2015)) along the value chain.

Actors and roles of the value chain

The model includes six different roles: *material supplier, parts manufacturer, product manufacturer, service provider, user, and recoverer*. The main material stream starts from the material supplier role, and with each subsequent step, more value and labour is added to the material until the product is delivered to the end user. Most of the roles are self-explanatory; material suppliers supply raw material to the material stream (e.g. raw cotton or viscose), parts manufacturer uses the raw material to produce parts (e.g. yarns, dyes), and the product manufacturer assembles the parts into a final product (fabrics and finished clothing). The service provider (retailer) then sources the product and distributes it to users or uses it as a part of its services.

One actor can fulfil several roles, and in theory all roles except for the end user could be fulfilled by a single actor. In some cases, a single company may supply the raw materials, spin the yarns, manufacture the fabrics and clothes and finally distribute them to consumers. Alternatively, these roles could be fulfilled by four separate companies working in partnerships or in transactional relationships.

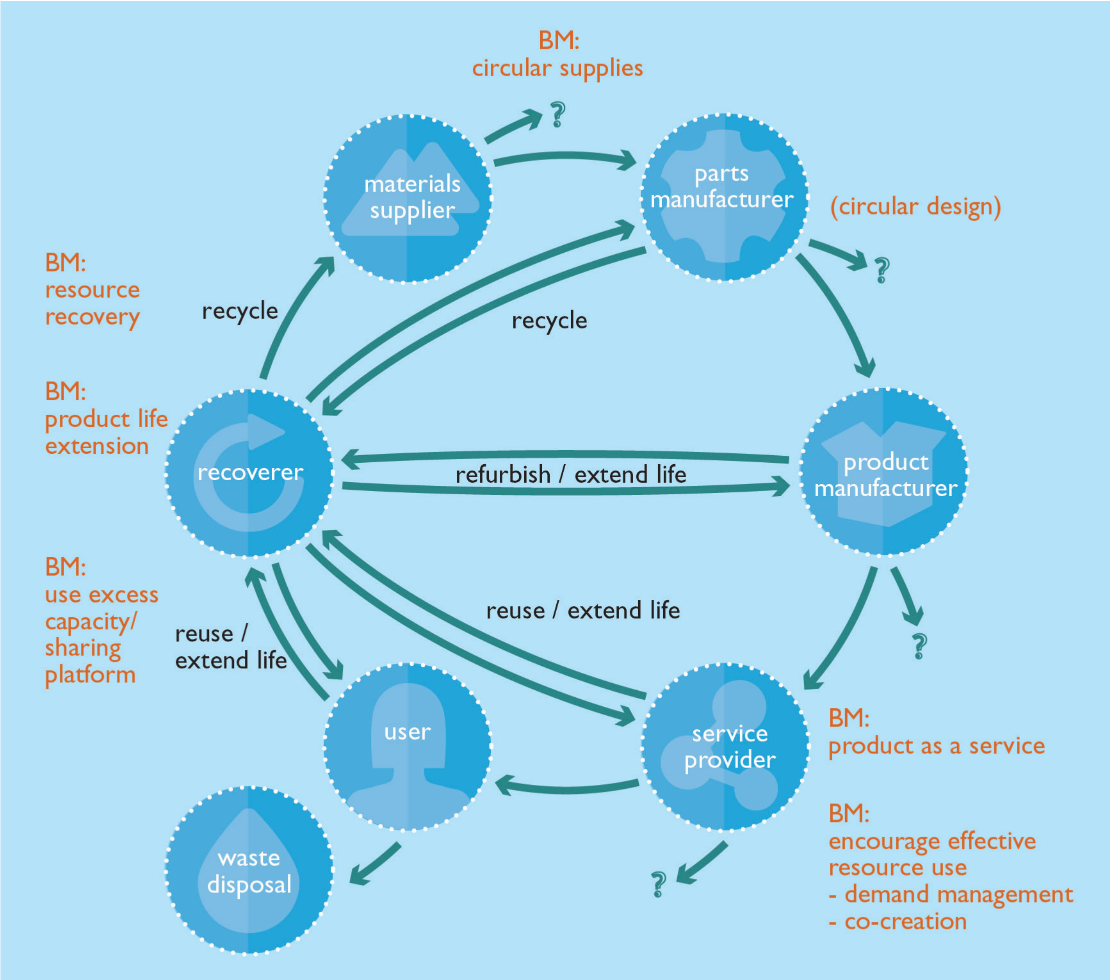

Figure 7. Model of circular economy used in the analysis of results of RECIBI project. The actors and their roles are represented by the circles, circular material flow cycles by arrows with white text and potential business models (BM) by red text. Source: authors own compilation based on EMF 2013a, Accenture 2104 and Sitra 2015.

The role of the recoverer is less obvious and requires more elaboration. The recoverer is an organization that captures the waste streams from other actors in the value chain and then resupplies these back to the value chain. The supplied product is reused, refurbished, or recycled, depending on product's prior condition. This is supplying and resupplying is represented by the double arrows in the model, and depending on the condition of the resupplied product, it is either returned to parts or product manufacturers (recycling or refurbishing), or returned for reuse for retailers or end users. As with the other roles, the role of the recoverer can be taken up by one of the companies within the value chain, for example, a product manufacturing company. Alternatively, the role can be fulfilled by company specializing in waste recovery business models.

Aside from the roles just discussed, the model includes six distinct, but related business models that were identified by Accenture (2014) and Sitra (2015). In this report, we use the term business model to refer to a company's primary revenue generation logic. The business models of the model include the following: circular supplies, product as a service, encourage effective resource use (demand management and co-creation), resource recovery, product life extension, and sharing platform. They have been used in the analysis of this case study, and will now be introduced in more detail.

Circular supplies

Companies with a circular supply business model provide their customers with renewable, recyclable, or biodegradable raw materials. Non-renewable materials and materials that are difficult to recycle are phased out. The company's main revenue comes from providing such materials. An example of the circular supplies business model examined in the RECIBI project is Spinnova, which is a Finnish company developing novel wood-based fibres for textile use.

Product as a service

The product as a service business model applies to situations where a product is rented or leased out to customers instead of selling it. Because ownership is not exchanged along with the product, responsibility for the products maintenance and end-of-life disposal remains with the company. This shift from ownership to access has two primary effects. On the one hand, this incentivizes the company to focus on product and service performance, instead of sales volume. On the other hand, companies with Product as a service business model are able to ensure that the products are reused, refurbished or recycled after their primary lifetime has ended. For example, Nurmi Clothing and FilippaK are developing a clothing as a service rental scheme for consumers. The service would allow customers to flexibly pick and wear clothes from the businesses without exchange in ownership.

Encourage effective resource use: Demand management

The demand management business model refers to companies that use systems, software, and forecasting techniques or other communication channels to manage their resources and material stock more efficiently (Sitra 2015). In the textile industry, particularly the elimination of dead stock is seen as a promising opportunity. When implemented correctly, the effective resource use business model could lead to drastic decreases in waste as well as lower warehouse and production costs. A good example of this kind of business model in the textile industry is Zara. Although Zara is notorious for fast fashion, the company is also well-known for using real-time sales data and 'just in time' principles in its production. Zara tests different variants of a product and, based on sales volume, the most popular variation is produced in larger quantities.

Encourage effective resource use: Co-creation

The *co-creation* business model is based on designing the final product or service with the help of the customer. By co-creating the offering with the customer, companies are better able to serve each customer's specific needs, which ideally prevent overstocking a product. When all products are 'fit for purpose', fewer resources are wasted by producing unwanted offerings. For example, YR is a company that uses an interactive design tool to produce live-printed garments in events and retail stores. The user can use the YR tool to choose from different patterns and effects to design a garment that is then printed and pressed within 10 minutes.

Resource recovery

The resource recovery business model is based on recovering the embedded value of a used product and using the recovered value in other products and services. Ideally, the products are not only recycled, which typically results in losing some of the embedded value. Instead, the value of the materials is retained or even increased by using innovative technologies and upcycling techniques. One example is the Finnish startup, Pure Waste Textiles, which buys textile waste from textile manufacturers in India, sorts the waste by color, shreds the fabrics to cotton fibre, spins the cotton into yarns, and finally turns the yarns into new textiles. Another example is Stormie Poodle in Sweden, which upgrade used obsolete hotel textiles into children's clothing.

Product life extension

Companies using the product life extension business model make profit by repairing, remanufacturing, upgrading and/or remarketing products. The underlying purpose is to extend the lifetime of products as long as is technically and economically feasible. The main source of revenue comes from either reselling the products or from providing product life extension as a service. For example, Nudie Jeans and Houdini offer repair services although that is not their main source of revenue. Dressmakers and tailors that provide clothing repair services are classic examples of product life extension businesses in the textile industry.

Use excess capacity / sharing platform

The *use excess capacity*, or *sharing platform* business model refers to companies that make profit by enabling the use of existing assets and resources in new ways. This is done through a physical or online platform that enables direct interaction between two or more market actors. An already classic example of this is Airbnb, which connects travellers and home owners under the Airbnb marketplace. Examples from the textile industry include We Started This and Rekki, which are online platforms for selling used clothing.

4.4.2 Circular material flow cycles in the textile sector

In the following section and in Table 5, examples of the various material flow cycles found in the study are presented.

Reuse/ extend life

In the *reuse / extend life* material cycle, clothes and textiles at the end of their first life cycle are given minor repairs (when necessary) and are returned either directly to consumers or to a service provider (Figure 7). The service provider then sells or leases the products back to consumers.

Traditional actors in the reuse / extend life material cycle include charities such as UFF, Salvation Army, Emmaus, the Red Cross, Stadsmissionen, and Human Bridge. These organisations sort the clothes for second hand stores, donations, development aid, recycling and waste disposal. This manual sorting often includes social aspects since they offer work to people that previously have been excluded from the labour market. One of the charity organisations in Sweden, Human Bridge, has recently started a specialised sorting plant, ReturTex, in co-operation with the Boer Group, which is a commercial actor in the European textile sorting sector. They use manual methods for sorting of hundreds of fractions. Automatic sorting is desired to separate materials, blends of materials, colours, and chemical contents. In Finland collection and sorting of worn-out textiles has so far been carried out only in temporary campaigns, typically waste management companies recommend that clothes are disposed of among dry mixed waste which will be incinerated.

The charity activities have been amended by take-back schemes of clothing retailers such as Finlayson, H&M, Nudie and Filippa K who actively advertise their take-back schemes for textiles either campaign-wise or continuously. Some advertise that as much as 50% of the collected textiles can be recycled in some way. Some of these retailers send collected textiles to large sorting companies abroad. In some cases, they offer value vouchers to the customers for the collected clothes.

The huge differences in value of collected textiles is an important aspect: some garments could be re-sold on the domestic market at reasonable (sometimes very high prices for specific vintage garments) or lower prices, while lower grades are exported at even lower price. Other textiles or garments are only suitable as low-grade raw material for other products. In addition, much is just considered waste and imply a cost for the collecting organisations to dispose of. Thus, the valuable items must first pay for handling and disposal of waste-grade textiles before a revenue is generated for the charity organisation or the commercial sorting plant. Beside the market value, textiles could be valued as for fit-to-use but donated to people in need.

There are also examples of textile brands, for instance Nudie and Houdini, that re-sell collected their own branded clothes on behalf of the customer. Another example is the birth of various second-hand shops for clothing exemplified by We Started This, which is a Finnish second hand online store that focuses on reselling used high-end clothing. There are also several initiatives for textile lifetime extension through sharing, leasing, repair services, etc. Both Nudie and Houdini offer repair services for broken products of their own brands, in their own shops, but can also deliver repair kits and instructions to customers far away from their shops. Examples of leasing of clothes include such as sportswear by Houdini and fashion and formal wear by Filippa K.

Refurbish/ extend life

The *refurbish / extend life* material cycle involves more extensive repairs and refurishing processes than the reuse material cycle (Figure 7). Products in the refurbish cycle may have gone through several life cycles or have been unusually damaged in use. The recovery process may require the use of more advanced technologies, but ideally the products would have been designed for refurbishment and repairing.

The end product of the refurbish / extend life material cycle is either a refurbished version of the old product or a new product that is made from the fabrics of old products. These new products could either be produced from recycled post-consumer fabrics (Globe Hope, Nudie Jeans, Stormie Poodle) or from textile industry waste (Nurmi Jeans, Pure Waste). This means that the properties of fabrics are not changed, only the use. It represents a scenario in which otherwise-to-be-wasted clothes and fabrics are repurposed into new products. In order to get the material for the production, the issues of collection and sorting need to be addressed. Clothes and textile products made of recycled materials are still mainly specialty products that are created either by small artisan producers or special products of larger producers. For instance, some sportswear and outdoor apparel producers, such as Klättermusen and Houdini, offer extended repair services. Nudie jeans collect used items of their own brand and some of the collected items are used to produce repair patches or remade into smaller accessories such as hats or simply cut into strips for production of rag rugs. The Stormie Poodle is collecting discarded but functional textiles such as bed sheets and towels from hotels and use these as input material for making children clothing. The items are produced by a social project in Latvia.

One step largely missing from the circular economy consortia are the designers of textiles and clothing. According to RECIBI informants there are plans for Nordic guidelines for the design of textiles for recycling but the topic is still largely under development (H&M). Recycling of textiles is hampered by mixed materials in many clothes, e.g. certain substances, prints, add-ons, buttons and zippers. The latter can be separated by mechanical means but according to our informants the mixed fibres are most challenging.

Recycle

Finally, the recycle material cycle is relevant for those textiles and products that are no longer repairable, but need to be returned to the production of primary textile fibre materials and yarns (Figure 7). Depending on their condition, textiles can either be returned to material suppliers (fibres) or parts manufacturers (yarns). Recycling can be either mechanical where the recovered textiles are shredded and the resulting fibres are spinned to new yarn, or chemical where the shredded fibres are dissolved and recovered as new fibres.

Recycling of worn-out textiles is the least developed area of circular economy of textiles. At least four major areas of activities need to be developed: design, improved sorting, new paths for recycling of textile fibres, and design for recycling. Fibre recycling is divided into mechanical and chemical recycling. In addition, there is a small segment of actors that upcycle unwanted textiles into new products of higher value.

An example of a mechanical recycler is Pure Waste Textiles, which is a Finnish clothing company that produces clothes from pre-consumer textile waste. The end product is a textile fabric that is either sold directly to other clothing companies or upcycled by Pure Waste Textiles into knitted fabrics, accessories and garments that are sold under the brand Costo. In Sweden, Houdini has some items in the assortment produced from Teijin (polyester) fibres. It is intened that such can be collected to be reprocessed into new fibres when discarded. Nudie Jeans (and a few others) have experimented with blending virgin and mechanically recycled cotton fibres in new fabrics for clothes. These experiments have all terminated due to quality reasons. However, there is research and development in mechanical recycling of, mainly pre-consumer textile waste. A demonstration shredder is running at Swerea in Mölndal, Sweden.

An example of chemical recycling is the Biocelcol dissolving technology, which is based on enzymatic treatment of chemical pulp and can be used for dissolving viscose-based textiles back into fibres. Biocelcol was developed in collaboration with VTT and Tampere University of Technology.

In Sweden research and development in chemical recycling attends to fibre decomposition, chemical content, material blends, and hazardous substances. One large Swedish actor in the textile business claims that chemical recycled fibres have a better defined composition, i.e. better chemical control, which is considered a very important advantage over mechanically recycled fibres. Sweden has a number of strong R&D centres focusing activities in chemical textile recycling at for instance Swerea/IVF, SP, Inventia, Chalmers, KTH, and the School of Textiles, located in Borås. There is capacity for running pilot and demonstrations of the methods in laboratories. The first Swedish demonstration plant for chemical recycling of cellulosic fibres is currently being constructed (Re:newcell expected to produce from early to mid 2017).

Value cycle and ecosystem development

A major challenge when seeking new possibilities for recycling textiles, or for developing novel processes for cellulose-based fibres, is that the projects working on these areas are mostly acting separately. Development of circular bioeconomy initiatives will likely require broad cooperation of actors to develop solutions to all bottlenecks in the chain. In this study, a number of initiatives in both Finland and Sweden were found in which broad consortia seek solutions for circular bioeconomy of textiles.

One of the most notable Finnish cases is a consortium called TEKI, or The Relooping Fashion Initiative (VTT 2015). Coordinated by VTT, the TEKI consortium has been involved in both developing solutions for recovering used cotton textiles and in experimenting with the processing and spinning of new fibres. According to RECIBI informants, the production of prototype clothing is still in the planning phase, but these projects have already proved that the novel viscose processes, whether based on cellulose carbamate or the Ioncell F -process, are able to use recycled fibres. Both mixed fibres, like polyester-cotton, and particularly cellulose-based fibres such as cotton, have been successfully used in the processes. Furthermore, a spinoff company called The Infinite Fibre Company was founded in 2016, and aims to commercialize fibre processing technologies. These can be seen as important steps towards circular bioeconomy in the textiles sector.

Another good example is the Topinpuisto circular economy park in Turku, Finland, which is coordinated by the regional waste management company Lounais-Suomen Jätehuolto Oy. The purpose of the park is to act as an open pilot platform for researching, developing and showcasing circular economy solutions. The park is still in its planning phase and the consortium consists mostly of actors in the waste recovery area.

In connection to this initiative, ta textile waste collection pilot called Tekstiili 2.0 was conducted. In addition to the actual collection and sorting, the pilot examined business models for using the collected textiles. The next step of Tekstiili 2.0. has been the launch of Telaketju, a Tekes-funded, collaborative project that aims to build a community of companies and public sector actors that could eventually form a national textile waste recycling network. However, existing partners are still generally limited to research organisations and actors in the waste recovery industry. The planned network would entail the whole value chain of waste textiles, and would enable refurbishing damaged textiles for new uses. Desired outcomes for the network include a unified model for recycling waste textiles, job creation, finding ways to improve overall material efficiency, and new export opportunities.

The cross-sectoral R&D programmes in Sweden aim at combine and include actors from R&D, academia, textile industries and trade, the second hand and charity sector, regional development bodies, waste management actors, etc. in order to conduct experiments and investigate opportunities for new ways of organising value chains as cycles. Most are still in experimental stages, such as finding beneficial use of mechanically shredded textiles, new ways to collect textile waste, combining lease and sale, and connecting waste disposal/textile collection directly to the second-hand sector.

Photo: Image bank of the Environmental Administration/ Esa Nikunen

Table 5. Examples of circular bioeconomy textile activities in Finland and Sweden.

Case	Short description	Stage of development	Phase(s) and business model	Collaborators
				Finland
Topinpuisto Circular Economy Park	A plan for a circular economy park in Turku, Finland.	Pilot	Recover; multiple	Ekopartnerit Turku, Gasum Biovakka, Kaivoasema, Kuntec, Kuusakoski Turun palvelupiste, Rudus, Smart Chemistry Park, Turku Science Park, Lounais-Suomen Jätehuolto Oy, Turku University of Applied Sciences. http://www.topinpuisto.fi/info/
Tekstiili 2.0	A textile waste collection pilot carried out in 2016 in Southwest Finland.	Pilot	Recover; resource recovery	Lounais-Suomen Jätehuolto Oy, Turku University of Applied Sciences, Globe Hope, The Finnish Red Cross, Salvation Army, Emmy, Ekokem, Texlove artisan association, Municipality of Turku, Sitra, Waste Association, Ekokaarina recycling centre. https://kumu.io/poistotekstiili/poistotekstiili#tekstiili-20/tulokset
Telaketju	A collaborative project aimed at building a national textile waste recycling network.	Pilot	Recover; multiple	Lounais-Suomen Jätehuolto Oy, Turku University of Applied Sciences, VTT http://poistotekstiili.turkuamk.fi/telaketju/
Pure Waste Textiles	A company selling pre-consumer waste to textile companies	Commercialised	Recover; resource recovery	https://www.purewaste.org/company/about-us.html
Finlayson take-back pilot	Finlayson collected bed sheets and linen that were turned into rag carpets	Pilot, commercial campaigns	Recover; resource recovery	Finlayson, HAMK, Hki Recycling centre, Suomen Nauhatehdas, Dafecor, Värisävy Oy, AL Monityö Ky, Rykkeri Ky http://www.marmai.fi/uutiset/vie-vanhat-lakanat-finlaysonille-yhtio-valmistaa-niista-rasymattoja-6310235
Ioncell-F	Ionic dissolvents that are capable of dissolving cellulosic waste material without addition of toxic chemicals	R&D	Recover; resource recovery	Aalto University, Helsinki University, VTT, Marimekko, Stora Enso http://puu.aalto.fi/en/research/research_groups/biorefineries/ioncell_f/
We Started This	A Finnish second hand online store that collects and remarkets high quality used clothing.	Commercialised	Recover; sharing platform	http://wst.fi/

The Circular Economy of Textiles (TEKI) project	A project that aims to model and pilot a closed-loop textile waste eco-system.	Pilot	Recover; resource recovery; circular supplies	VTT, Helsinki recycling centre, SUEZ, Pure Waste Textiles, Seppälä, Repack, Ethica. http://www.vttresearch.com/media/news/unique-production-experiment-in-progress-turning-waste-cotton-into-new-fibre-for-the-fashion-industry
TEX-VEX experiments	Local textile take-back schemes for sorting and reselling used consumer textiles.	Pilot	Recover; product life extension; resource recovery	TEXVEX Forssa, TEXVEX Loimaa, TEXVEX Humppila, TEXVEX Hämeenlinna, KILOilo Hyvinkää, Häme AMK (Kirsi Sippola), municipalities, Syke, eco-design companies such as Ilomar. http://www.hamk.fi/tyoelamalle/hankkeet/poistaripaja/Sivut/texvex-forssa-ja-texvex-loimaa.aspx
KIHU	A pilot project that looked for a way to recover and reuse gypsum and felt root from construction waste in textile recycling.	Pilot	Recover; resource recovery	HSY, Päijät-Häme regional waste co-operative, Ladec, Gypsum Recycling International, Tarpaper Recycling Finland, Saint-Gobain Rakennustuotteet Oy, NCC Roads Oy. https://www.phj.fi/ajankohtaista/74-yhtioe/302-kihu-kipsi-ja-kattohuopajatteiden-kerays-kierratykseen
Dafecor	A company that manufactures and sells products made from textile residues.	Commercialised	Recover; resource recovery	http://dafecor.fi/
Biocelcol	A dissolving technology based on enzymatic treatment of chemical pulp.	R&D	Recover; Resource recovery	VTT and Tampere University of Technology. http://www.vtt.fi/palvelut/biotalous/korkean-suorituskyvyn-kuitumateriaalit/uusiutuvien-kuitujen-l%C3%A4hteet/puupohjainen-tekstiilikuitu
NEXTIILI	A Tampere-based textile take-back scheme modeled after the TEX-VEX experiments.	Pilot	Recover; product life extension; resource recovery	Pirkanmaan Kierrätys- ja työtoiminta ry (Recycling centre); Ekokumppanit, Pirkanmaan Jätehuolto Oy, Suomen poistotekstiilit ry, UFF, Dafecor. https://www.nextiili.fi/
Celluloce cabarmate	Urea-based dissolving technology for virgin or used cellulose.	R&D	Recover; resource recovery	VTT, Tampere University of Technology, MTT Agrifood Research Finland and KCL Keskuslaboratorio. http://www.vttresearch.com/services/bioeconomy/high-performance-fibres/sourcing-renewable-fibres/wood-based-textile-fibres-2

Sweden				
re:newcell	Chemical dissolving of textiles for the making of textile pulp	Demon-stration commer-cialisation	Recover Resource recovery	University of Borås, Smart Textiles, established business network, several R&D project partners http://renewcell.se/
ReturTex	Sorting of collected textiles	Commer-cialised	Recover /Sorting Resource recovery	Human Bridge, Boer Group, Avesta municipality, Public Employment Agency, IVL/SIPTex http://returtex.se/
Fastighetsnära insamling av textil	Trial on kerb side textile collection system	Pilot	Collection/ recover Resource recovery	City of Gothenburg Kretslopp & vatten, Renova AB, Bostads AB Poseidon, and Human Bridge http://www.mynewsdesk.com/se/renova/pressreleases/nytt-projekt-siktar-paa-oekad-aatervinningen-av-textil-960423
H&M	Novel viscose, collec-tion, fibre & material recycling, procurement of recycled fibre	R&D, commer-cialized	Collection, recov-ery Resource re-covery	Partner of several R&D projects such as ForTex, Cellunova, Mistra Future Fashion, with Innventia, SP, Swerea. Also with Aalto and VTT. Businesses such as IKEA, Kering, Worn Again, I:CO, SOEX and more. http://about.hm.com/en/sustainability.html
Organoclick	Toxic free repellent	Commer-cialised	Use De-toxification of materials	Academia, Organoclick has been part of EU projects with many actors but with unclear roles and responsibilities. http://organoclick.com/products/performance-textiles-nonwoven/
Nudie Jeans	Extension of life time, repair, re-sell, material recycling, fibre recycling	Commer-cialised, trial/pilot	Recover Product life extension; Resource recovery	Participate in some major textile R&D projects such as Mistra Future Fashion together with other businesses and research institutions such as Swerea, Inventia, SP, IVL, aca-demia, etc. https://www.nudiejeans.com/page/this-is-nudie-jeans
Houdini	Design for long lifetime, fibre recycling, rental, repair, reuse/re-sell	Commer-cialised	Recover Product life extension; Resource recovery	Suppliers, Bluesign, major textile R&D projects such as Mistra Future Fashion in col-laboration with research and industry partners, Stockholm Resilience Centre http://houdinisportswear.com/en/sustainability
FilippaK	Design for long lifetime, recycled material, collec-tion, lease	Commer-cialised	Recover Product life extension; Resource recovery	Major textile R&D projects such as Mistra Future, BioInnovation/establishing locally grown textiles in Sweden, in collaboration with research and industry partners. https://www.filippa-k.com/se/filippak-world/front-runners
Stormie Poodle	Upgrading recycled textiles into new clothing	Commer-cialised	Recover Resource recovery	http://www.stormiepoodle.se/
Wargön Inno-vation	Facilitate textile recy-cling	R&D	Incubator	Participate in several multi-partner research and development projects such as Mistra Future Fashion, BioInnovation/establishing locally grown textiles in Sweden, Textiles back to textiles, CelluTex 2.0, re:textile, which comprise both industry partners, aca-

				demia and research institutes. https://wargoninnovation.se/en/home-en/
Swerea	Dissolving techniques, mechanical shredding, recycling models, etc.	R&D Pilot	Resource recovery	R&D centre involved in research with a wide variety of organisations. Member of RISE – Research Institutes of Sweden -, together with among others SP and Innventia,
IKEA	Novel viscose, collection, fibre & material recycling, procurement of recycled fibre	R&D, pilot, commercialised	Collection, recovery Resource recovery	Partner of several R&D projects such as ForTex, Cellunova, Mistra Future Fashion, with Innventia, SP, Swerea.
Kretsloppspark en Alelyckan	Circular economy park in Gothenburg	Commercialised	Recover, reuse, recycle Multiple	City of Gothenburg, Återbruket (used building material), Stadsmissionen (charity, 2nd hand sale of clothing, household items, furniture, etc.), Returhuset (repair, refurbish, upgrade of used products, café, social employment) http://goteborg.se -> Avfall och återvinning -> Hur lämnar hushåll avfall -> Kretslopps-parken Alelyckan

4.5 Potential environmental impacts

4.5.1 Textile life time environmental impacts

As has been discussed, the global textile market could become more sustainable by utilising technologies developed in Finland and Sweden for the production of novel regenerated cellulose fibres, as well as recycled fibres. Novel wood-based fibres can be used in textiles to substitute less sustainable fibres such as cotton, traditional viscose and polyester. The novel fibre technologies could contribute to a significant reduction of environmental degradation caused by both textile fibres production and textiles production (Table 6).[5] Utilisation of boreal forests for textile fibres production instead of agricultural land needed for cotton cultivation could significantly reduce land use pressure, pesticide use and water consumption. Replacement of polyester fibres to a higher degree with new wood cellulose fibres would decrease the use of fossil raw materials. An additional aspect in favour of man-made and natural cellulosic fibres such as cotton and viscose is that synthetic textiles release microfibres when laundered. These fibres reach recipient ecological media and there is increasing concern that the can cause severe harm as they accumulate in the aquatic life due to the slow decomposition of these fibres (Setälä et al. 2017).

Mixing textile fibres in a garment makes repairing and recycling less attractive, as does the incorporation of decorations and electronics. Development of well-functioning collection, sorting and recycling systems for worn-out textiles would offer raw material for the novel technologies that are designed also for the use of recycled cellulose fibres. The use-phase, i.e. washing, can dominate life cycle impacts.

Table 6. Important environmental impacts of textiles production and consumption (based on Judl et al. 2016, and the references therein).

Climate impacts, energy consumption and atmospheric emissions
Climate impacts of commonly used textile fibres production vary significantly depending on the type of fibre and are reported to be between 2 and 9 tonnes of CO_2-eq per tonne of fibre. Production of cotton fibre typically causes less climate impacts than polyester or viscose production. Climate impacts of the new wood-based regenerative fibres can, however, be as low as 1 tonne of CO_2-eq. per tonne of fibre. Energy is consumed in further processing of fibres into fabrics and textile products. Moreover, production of dyes and chemicals needed in textiles treatment contribute to climate impacts and can in some cases cause even higher climate impacts than final production of textiles. Air pollution is caused by fossil fuels combustion for energy, operations of machinery and transport along the long supply chains. The use phase can dominate life cycle climate impacts and energy consumption is affected by factors such as laundry temperatures. Globally, most used textiles still end up in landfills or incineration. The decomposition of textiles at landfill contributes to carbon dioxide and methane emissions.
Resource depletion
Being fossil-based fibre, production of polyester contributes to the depletion of non-renewable natural resources. However, the production of natural fibres, such as cotton, also requires large amounts of energy, in particular for cultivation and in the production of fertilizers and other agrochemicals. Transport of textiles also relies on fossil fuels. Production of solvents and other process chemicals, such as dyes, also contributes to the resource depletion.
Water use
Production of cotton is water intensive due to irrigation and some of the main producing countries are already under a water stress (e.g. Uzbekistan: 4% of global cotton production, the 30th most water stressed country).

Globally, cotton production is responsible for about 3% of the global water use.

Processing of fibres into a yarn, a fabric and further pre-treatment of textile products requires between 5 m^3 (for oil-based fibres or cotton) and 11-42 m^3 (for traditional viscose) per tonne of fibre. Moreover, water is consumed during the use phase of textiles in laundering.

Hazardous substances

Solvents used in fibre production can be a source of pollution of hazardous substances. Viscose process uses carbon disulphide, which is hazardous. Production of dyes, and the dyeing process itself, are major sources of water pollution especially in production facilities with inadequate water purification systems. The use of pesticides in cotton cultivation contributes to serious water pollution in many regions. Polyester microfibres released during wash hinder usage of sewage sludge and accumulate to seas (Sillanpää & Sainio submitted; Talvitie et al. 2017).

Land use

Cotton production competes for land against other crops and increased production of cotton will compete with food production.

Waste and recycling

Textile collection, sorting, reuse and recycling activities in the Nordics are largely unregulated and undeveloped. The current form and scale of waste textile collection schemes present a major obstacle to realising textiles recycling. Collected textiles for recycling are often transported long distances, which would favour local sorting. Moreover, fibre blends and the use of mixed materials in a single product make recycling a challenge. As a result, most textiles end up in mixed municipal waste and subsequently in incineration. In Finland 82% of all waste textiles are incinerated, while in Sweden some 55% enters municipal waste streams and circa 25% is unaccounted for.

4.5.2 Macroeconomic potential of textile remanufacturing

Economic and environmental implications of implementation of two different textile scenarios and their joint implementation were assessed by the ENVIMATscen model[8] developed for a long-term simulation of the Finnish economy. The assessment included the following scenarios:

1. **Longer wearing**: Wearing time of household textiles and clothes will double and it will decrease annual textile and clothes purchases in households.
2. **More viscose**: Half of imported textile and clothes will be substituted by domestic viscose textiles. Viscose will be produced in domestic pulp industry.
3. **Joint**: ‘Longer wearing’ and ‘More Viscose’ scenarios are implemented simultaneously. The result is not the sum of separate scenarios but less, because they counteract the individual impacts to some extent.

Model and basic scenario

ENVIMATscen is an environmentally extended long-term simulation model. The base year is 2010 and the model is solved to the chosen end year assuming that the relevant variables develop along steady growth paths from the base year to the end year. The model is extended with a number of environmental indicators. These include *inter alia*: raw material consumption (RMC), greenhouse gas emissions and sinks, other airborne emissions and water releases, land use and biodiversity loss generated by economic activities.

In the impact assessment of textile scenarios, the starting point is the basic scenario of general economic development. The economy grows from 2010 to 2030 at a rate of around 1%/year. The energy system will develop according to the Finnish energy and climate strategy of the Ministry of economic

[8] Model developed in the Sustainable Use of Natural Resources and the Finnish Economy (SURE) –project (2012-2016), funded by the Academy of Finland.

affairs and employment. The overall economic effects of the scenarios are analysed by ENVIMAT^{scen} model till the year of 2030.

Scenario 1 (Longer wearing)

In the consumption expenditure of households, commodities of Clothes and fabrics (COICOP[9] 13) and Household textiles (COICOP 052) also include repairing and maintenance. Additionally, the purchase price of commodities includes trade margins and value added taxes.

The duplication of wearing time of textiles and clothes were modelled by halving shares of basic-priced textiles and clothes in the consumption expenditure of clothes and textiles, 20 % of it was directed to additional costs of clothes' repairing and 20% to extra use of laundry services. Additionally, one factor related to lengthening of wearing time is increased sales of reused clothes and textiles. In the national accounts, from the purchases of reused goods only trade margins are entered into the household expenditure. Therefore, the share of trade margins also was raised by 20%.

The quality improvements due to the longer use of clothes and textiles were taken into account by duplicating the investments for research and development (R&D) of textile and clothing industry.

The changes will lead to the decline of usage costs of textiles and clothes. Cost savings were considered to target to additional consumption of other consumer goods and also additional consumption of textiles and clothes in the relation of income elasticity of consumer goods. Naturally, changes of general economic development have an effect on household incomes and thus on consumption.

Scenario 2 (More viscose)

In the 'More viscose' scenario, imports of textiles and clothes of the basic scenario are halved. It also affects textiles used as intermediate products in clothing industry.

In modelling viscose pulp it was assumed that 70% of domestic textile production will use viscose fibre. Viscose pulp is manufactured in domestic pulp industry. The manufacturing of viscose fibre would occur in the economic activity 'Manufacturing textile fibres' (TOL206, Finnish Classification of Economic Activities). At present, there is no viscose pulp production in Finland – only in the minor extent manufacturing of synthetic fibres. Therefore, in the ENVIMATscen model viscose fibre production is modelled directly inside textile industry.

In the model, production and product volumes are based on price level in 2010. Prices per kilo are the following: clothes 35.8 euros/kg, textiles 7.01 euros/kg, viscose fibre 1.2 euros/kg, and viscose pulp 0.53 euros/kg. In the textile production level of 451 Meuros (2010) the value of viscose pulp would be 24 Meuros. The value of viscose fibre (48 Meuros) is additional production within textile industry, it is added to the value of textile production and as intermediate input from itself to itself.

Results of scenarios

The result of overall economic effects in 2030 indicate an improvement of GDP and employment, but at the same time it can be seen that there is growth in raw material consumption and greenhouse gases in both scenarios compared to the basic scenario (Table 7). However, GHG intensity (GHG/GDP) is improving contrary to resource intensity. It is noteworthy that joint effects are less than the sum of the separate effects of scenarios. For example, GDP grows in the joint scenario 5.14 billion euros, while the sum of the 'Longer wearing' and 'More viscose' would be 6.21 billion euros.

The raw material consumption of the economy increases in all scenarios. In the 'Longer wearing' scenario the effect stems from direction of consumption away from consumption of textiles and clothes towards other commodities, which often are more material intensive than textiles. Similarly, in the 'More viscose' scenario the substitution of synthetic fibre textiles with wood-based viscose textiles raise

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[9] Classification of individual consumption by purpose (COICOP) developed by the United Nations Statistics.

material consumption. Greenhouse gases also rise, but less than economic growth, as a result emission intensities reduce.

Table 7. Overall economic effects of the 'Longer wearing', 'More viscose', and joint scenarios in 2030, the figures are changes from the level of the basic scenario.

	Basic	Wearing	Viscose	Joint
GDP, Billion € 2010 prices	228	+4.5	+2.7	+6.1
Employment, 1000 fte*	2497	+50.8	+37.5	+72.3
Raw material consumption (RMC), Mt	164	+4.7	+2.9	+6.4
RMC/BKT, g/€	717	+6,2	+4.3	+8.8
Greenhouse gases, Mt CO_2 eq	45	+0.6	+0.4	+0.8
GHG/BKT, g/€	199	-1.4	-0.8	-1.9

*fte = full time equivalent

Effects of the scenarios on domestic textile and clothing industry's value and employment are presented in Table 8. In the 'Longer wearing' scenario the consumption of textiles decreases in which case also employment in textile industry decreases. In the 'More viscose' scenario above, all the replacement of imports to domestic production increases the production value and employment.

Table 8. Effects on textile and clothing production values and employment in the scenarios.

	Basic	Wearing	Viscose	Joint
Production value, Meur 2010 prices	914	-49	+1831	+1079
Employment 1000 fte	9.9	-0.3	+11.9	+7.0

From the viewpoint of households, it is noteworthy that in the 'Longer wearing' scenario consumption expenditure reduces only around 14 % because costs also include trade margins which increase. It is also partly influenced by the rebound effect of the general economic growth. In general consumption moves towards other goods and services (Table 9). Rebound effects also cause more environmental impacts at the same time with economic growth.

In the 'More viscose' scenario the increase of prices of textiles and clothes by 6% restrains their consumption compared to the general growth. Raw material use increases along with the increase of viscose production, but the overall effect is not as great as in the 'Longer wearing' scenario due to the lower rebound effects. In the joint scenario, consumption is shifted from textiles to other goods and services.

Table 9. Household consumption expenditure in 2030 in the basic scenario and changes caused by textile scenarios, Meuros 2010 prices.

	Basic	Wearing	Viscose	Joint
Clothes and fabrics	4 847	-644	+18	-625
Household textiles	666	-99	-25	-109
Other goods	47 571	+1 282	+467	+1 550
Services	63 201	+1 849	+770	+2 312
Consumption expenditure total	116 285	+2 388	+1 230	+3 129

4.6 Relevant policies

The policy landscape around the bio-textile innovation system (Table 10) was analysed using an analytical framework based on the TIS functions as explained in section 2.6.

Policies and actions supporting niche creation

Novel wood-based fibres are currently developed in several large and cross-sectorial R&D projects both in Finland and Sweden, although without major considerations of circularity. In parallel, there is increased interest among major textile purchasers from both countries for recycling and re-use of textile fibres. However, apart from R&D funding contributing to *knowledge creation (C1) and influencing the direction of search (C7)*, few policies explicitly support growth and circular material flows in the emerging wood-based fibre subsector. The re-use of textiles and second-hand shops have been established mainly in the field of charity organizations. Recent actions promoting textile recycling have, in both countries, also been driven by large individual brands, e.g., Finlayson, H&M and IKEA or small-scale entrepreneurs and designers.

Entrepreneurial experimentation (C4) has been somewhat encouraged by expectations on forthcoming extended producer responsibility (EPR) systems particularly in Sweden.

Both in Finland and Sweden, new Acts addressing public procurement appear to be supporting *market formation (C2)* and may provide opportunities for wood-based fibres and elements of a circular economy. In both countries, the justifications for the Acts strongly emphasize procurement of innovative solutions. Emerging practice will be critical for market formation. EPR systems might accelerate textile fibre collection and recycling markets, but may also harm existing re-use markets if grandiose recycling targets are set and boundaries of ownership are not clearly defined. Besides, national EPR systems are more and more challenged because of increasing online shopping.[10]

Regime Destabilising Policies

Bans on the landfilling of biodegradable waste have promoted waste incineration instead of landfilling generally, but otherwise there are *no significant changes in regime rules (D2), new control policies (D1)* or polices targeted at destabilizing the dominance of cotton and fossil raw material in textiles. A reduced VAT for repairs recently introduced in Sweden could provide impetus to seek opportunities to re-use textiles.[11] In the long run decarbonisation may reduce *legitimacy (C6)* of fossil based fibres and textiles, but current climate policies do not give any consideration to materials produced outside of the EU. Likewise, mixed materials that cause increasing problems for recycling and re-use of textile fibres are not addressed by current product policies. Ecolabelling serves the function of providing consumers with new information on more environmentally sound product choices. The Nordic Swan label has criteria for textiles including requirements on among others chemicals and functionality. If recycled fibres are used, they do not need to fulfil the requirements for the production of fibres (Nordic Ecolabelling… 2016, p. 8).

[10] In principle, permit requirements for professional waste treatment might complicate handling of collected textiles. So far, this kind of textile related activity has been indirectly consented in both countries, but legal objections against experimental textile collection as well as potential threats for recycling were raised in Sweden.

[11] However, VAT reductions are constrained by the Annex IV of Directive 2006/112/EC on the EU's common system of value added tax. It narrows these reductions to 'minor repairing of (a) bicycles; (b) shoes and leather goods; and (c) clothing and household linen'. Proposals to amend the scope of reductions have been discussed in several member states.

Policy challenges and options

- Linking the development of novel wood based fibres with circularity e.g. by supporting the emerging broader networks of actors. Currently many actions stimulate fibre development but without considering circularity.
- Policies can be used to address mixed materials that cause increasing problems for recycling and re-use of textile fibres.
- Stimulating actors to establish commercial production based on the R&D results in Finland and Sweden.
- Visualising and communicating the environmental arguments regarding novel viscose and circular use of textiles.
- EPR systems may accelerate textile fibre collection, but may also harm existing re-use markets if boundaries of ownership are not clearly defined. The recovery of used textiles needs to be fitted into the global textile production and consumption chains and networks.
- A reduced VAT for repairs recently introduced in Sweden could give impetus to seek opportunities to re-use textiles. Tax on waste incineration may also be considered to encourage recycling in Finland (Salmenperä et al. 2016).

Table 10. Policy landscape around the bio-textile innovation system based on the TIS functions (C=creative, niche support functions; D=Destruction, regime destabilation functions).

Finland	**Sweden**
Knowledge creation, development and diffusion (C1)	
Limited R&D funding (only 0,2% of all Tekes funding was allocated to textiles and clothing manufacturing between 2010-2016[12])	In some publicly funded R&D projects, actors from several sectors are included in order to promote a product chain perspective.
Establishing market niches/market formation (C2)	
No explicit policies but the new Act on Public Procurement (1397/2016) may provide opportunities; voluntary take-back systems or EPR would enhance recycling	No explicit policies. Some regions purchases bio based products but not necessarily based on domestic content. Current preliminary proposals to make more use of public procurement from Tillväxtanalys (Growth analysis). Proposed EPR (Naturvårdsverket 2016b) would enhance recycling.
Price-performance improvements (C3)	
R&D funding to develop new and competitive production methods	Same as in Finland. R&D projects often multi-stakeholder.
Entrepreneurial experimentation (C4)	
Many experimental activities related to novel viscose, collection, recycling and test production.	A lot of experimental activities related to novel viscose, collection, recycling and test production.
Resource mobilisation (C5)	
R&D funding from Tekes, FP7 and H2020. Some mobilization in the textile business to prepare for expected EPR.	Limited. Some support through research and recycling testing, and general support for 2nd hand markets, which promote waste collection and sorting. Partly, the funding and research aims to create networks. Mobilization in the textile business to prepare for ex-

12 https://extranet.tekes.fi/ibi_apps/WFServlet?IBIF_ex=o_myonto_html&IBIAPP_app=openraho. The R&D funding gained by Finnish partners (companies, research institutes and universities) from FP7 and H2020 to 'textile –projects' equals the amount of funding from Tekes.

	pected EPR. The government has initiated several reports related to the bioeconomy, which may precede more targeted policies.
Support from powerful groups/legitimation (C6)	
Publicity for domestic products	Some large brands – e.g. IKEA and H&M - are actively seeking more sustainable solutions and participate in relevant projects. General drive to support 2nd hand markets and reuse, including ongoing government inquiries and VAT reduction. LCAs conducted in new projects aims at supporting new policies and measures. Textiles prioritized for circular economy measures.
Influence on the direction of search (C7)	
Increasing expectations, but the two main directions (novel viscose & textile recycling) mainly follow two different paths. No pressure or incentives from regulation. Articulation of demand from leading customers so far low.	Lack of focus or overarching vision. The two main directions (novel viscose & textile recycling) follow two different paths, with quite different practices. Both larger (e.g. Mistra Future Fashion) and more targeted research initiatives, often in collaboration with a limited number of recurring market actors.
New control policies (D1)	
None specific, but strict consumer protection legislation (Act on Consumer Safety 920/2011) ensures minimum standards. Ban on landfill of organic waste may enhance circularity (Decree 331/2013).	None specific. Waste related rules of some relevance. Several municipalities ease general textile collection for charity organizations, promote extending of use time, conscious laundering, etc.
Significant changes in regime rules (D2)	
None, but the new Act on Public Procurement (1397/2016) may change rules	None specific, though VAT reductions for 2nd markets are under discussion. The government has initiated a new cooperative program for "Circular and bio based economy" at the governmental level. An EPR scheme for textiles is expected in the near future.
Reduced support for dominant regime technologies (D3)	
None	See above.
Changes in social networks, replacement of key actors (D4)	
None	None

4.7 Concluding remarks

To sum up, there is a growing interest in the wood-based textile sector in Finland and in Sweden. Simultaneously there is growing pressure to find new circular solutions to the textile sector. These are reflected in interesting technical developments with novel viscose-type fibres. Ioncell appears as the most illustrative example, and multiple examples of small scale businesses and campaigns for reuse, refurbishing and recycling of textiles can be found in both countries. Seen as a whole, these developments offer new opportunities for the Finnish and Swedish manufacturing industries.

There are however a number of challenges to be overcome in order to support this development. The developments in Finland and Sweden are rather similar but differences were found in this study. They are summarized in Table 11 and also specified in the text.

The first main challenge is the early stage of development of the novel processes for regenerated cellulose. The quality of fibres has been ensured but the economics and resource-efficiency of the processes of e.g. IONCELL-F still require significant development before they are commercially feasible. When the basic problems of the process have been solved, the process development requires commercial partners. As in Finland both StoraEnso and Metsä Fibre and in Sweden both Domsjö Fabriker and Södra have participated in the development projects, one can assume that pulp producers may be potential partners. In parallel, there are the R&D needs for chemical dissolving of textiles, which is likely to be a requirement for successful large scale recycling. The classical problem of shortage of funding instruments for commercial-scale trials is present in this case.

Second, there is a pressing need for better collection of used textiles as the textile value chains are still largely one-way. This study found interesting initiatives for the collection of used textiles from households especially in Sweden. For consumers, there are collection systems that are in practice only fully functional for clothes and textiles. For worn-out textiles waste incineration remains the most obvious choice.

In order to create useful fractions from collected textiles, much more effective sorting is needed. This is a challenge to solve. In Sweden, there is an initiative for large-scale sorting of textile waste, however, such work is non-existent in Finland. Other channels are typically complicated, campaign-type or small scale. Many recycling actors collect their raw material from industrial pre-consumer waste.

In order to attract commercial operators for collection and sorting, the collected material should have market value, i.e. users for recovered material. As this is a typical "chicken-and-egg" problem, the development of circular economy solutions requires the cooperation of many different actors connecting the waste management side of the loop and the production chain. While a few such initiatives exist both in Finland and in Sweden, there is need for support for such co-creation initiatives that aim at commercial solutions. The ability of the novel processes for regenerated cellulose fibres to use recycled raw materials is an important asset that needs to be utilized in such broad consortia.

Table 11.Comparison of the textile sectors of Finland and Sweden.

	Finland	**Sweden**
Actors	Domestic textile production and design limited to small scale high end textile products. Research organisations developing novel wood-based fibres. Traditionally, charity organizations main actors in re-use, but recently many initiatives by large brands and small-scale entrepreneurs and designers. Currently most textile waste incinerated.	Several large global fashion brands dominate the sector. Design, development, logistics in Sweden but the production takes place mainly in Asia. Research institutions and academia develop novel viscose processes and processes for chemical textile recycling in collaboration with industry. Re-use similar to Finland. A specialized sorting plant recently started, but the majority of textile waste is incinerated. Emerging consumer awareness.
Processes of commercial scale operations	Artisan producers using recycled materials. More breakthroughs in developing wood-based fibres. Main volumes still linear.	Artisans and smaller designers using recycled materials, as well special products of larger producers, but not large-scale business. Demonstration plant for chemical textile recycling. First sorting plant for used textiles in operation.
Products	Main stream imported. Product lifetime relatively short. Potential in novel viscose and recycled fibres.	Similar to Finland. Some examples of repair and leasing of clothes.
Market formation	No significant global actors that would push the markets towards circular bioeconomy or wood based textiles.	Interest from major textile purchasers and brands may create demand for wood-based textiles and recycled materials.
Research and development	R&D in wood-based fibres has progressed to promising results (product development e.g. IONCELL- F). Initiatives for combining whole value chain.	Several large and cross-sectorial (forest-textile) R&D projects, as well as broad and inclusive R&D programmes combine actors from textile sector, collection, recycling, and academia/research institutions

R&D funding	Tekes dominates domestic funding, EU framework programmes important as well.	Multiple funding sources.
Policy	Few policies explicitly support transition towards circular bioeconomy in textile sector, landfill ban, strict consumer protection legislation and the new act on public procurement may promote circular economy.	Prioritised policy focus for CE supported by industries: New collection schemes, new business concepts: lease, rent, repair. Introduction of reduced VAT for minor repairs. Suggestions on extended producer responsibility.

One inherent challenge for the clothing sector is the phenomena of rapidly changing fashion. Within this paradigm, it is difficult to design clothes for a very long use time, and the trend for a long time has been towards short-lived and cheap clothing. There are, however, some emerging business models for high-quality second hand shops, renting and leasing of garments, remodelling of old clothes and so forth.

A fundamental underlying challenge for the textile sector is the high price of labour compared to the cost of materials. This has led to the economy of scale in the textile industry and effectively off-shored garment manufacturing from countries such as Finland and Sweden. Any major introduction of novel viscose production in Finland and Sweden opens up for possibilities for reshoring highly automated production such as spinning, weaving and knitting. These could develop into global consumer businesses if modern innovations such as new business models based on internet-based retailing, automated manufacturing, and so forth are properly utilized. This stated, it remains difficult to foresee re-shoring of garment manufacturing to the Nordic zone.

Photo: Johanna Kinnari

5 Circular bioeconomy in wood construction

The construction sector has potential to contribute positively to the bioeconomy by increasing the market share of multi-storey wood buildings; as Finland and Sweden share a tradition of wood construction in the detached housing segment and access to raw materials. The environmental arguments favour a shift to wood construction. Several innovations in wood processing and construction processes are available and commercialized. There is also potential for exports from Finland and Sweden, both in terms of material solutions and knowhow. However, the inherent complexity of buildings, with many actors (including powerful incumbents), intricate construction processes, high degree of regulation and long life times, makes the shift to circular bioeconomy inherently challenging.

5.1 Aim and methods

This case focuses on the outlook of multi-storey wood building and its potential to contribute to the renewal of the wood construction value chain; i.e. forest, building materials and construction, and real estate industries. Despite a strong raw material base, long traditions in wood processing and wood building as well as several government level support programmes, the market share of multi-storey wood buildings has remained rather low in the Nordic countries. In recent years, innovations in wood material and construction technologies—such as cross-laminated timber (CLT)—have demonstrated potential to contribute in the renewal of forest and construction industries and circular economy. This case aims to:

1. compare the multi-storey wood building field in Sweden and Finland,
2. identify the key public actors essential to decision-making,
3. identify the drivers and barriers multi-storey wood construction (enhancing bioeconomy), and
4. identify drivers and barriers to improved durability and recycling of building materials.

This case study is based on expert interviews (see Table 12), conference and building fair observations, a literature review of academic and trade publications, and evaluations and reports on related issues.

Table 12. Interviews for the wood construction case in Finland and in Sweden.

Finland	Sweden
Research on Real Estate Economy 1	Real estate investors 1
Real estate developers 1	Industrialised producers of wooden buildings (forest industry) 3
Real estate investors 1	Construction companies 2
Material producers (forest industry) 2	Specialist of reuse of industrial buildings (incl. reuse) 1
Construction company 1	Interest organisations: 2
Green Building Council 1	R&D funding: 1
Regulation in reuse and brownfield investments, Ministry of the Environment 1	

5.2 General characteristics of the construction sector

A number of characteristics of the construction sector have been identified which are common to most types of constructed products (Nam and Tatum, 1988). Construction is a complex undertaking due to the diversity of materials, equipment, products and their combinations, which has in turn led to the increasing specialisation of trades.

Constructed products have strong connections to public health and safety, and carry a high degree of social responsibility as they compose a significant part of the human environment. As such, the construction sector is highly regulated (e.g. in terms of fire, safety, environment, planning). Conservatism arises from the costliness and high social responsibility, and is evident in both producers and consumers. (Nam and Tatum, 1988)

Construction is a project-based activity relying on temporary coalitions of actors that coordinate to achieve a task in a specific time-space (Reichstein et al., 2005). This limits sustained interaction among actors making it difficult to transfer knowledge from project to project (Mahapatra and Gustavsson, 2008). Construction is site-specific (Nam and Tatum, 1988), with a notable exception being the prefabrication of building elements (Malmgren, 2014). Furthermore, there is uncertain demand for uniform buildings, products and materials as design and size of decisions are dependent on the choice of several stakeholders (client and architect) (Mahapatra and Gustavsson, 2008; Reichstein et al., 2005).

The construction sector is unique as it is dominated by small local subcontractors providing services to a small number of large contractors (Mahapatra and Gustavsson, 2008; Reichstein et al., 2005). This limits the innovative capacity of the system as small firms have little innovative capacity themselves (Reichstein et al., 2005) and the small number of large firms lack of competition, which leads to higher costs and lower quality (Mahapatra and Gustavsson, 2008).

The multiple actors involved in the construction process (e.g. clients, architects, engineers, suppliers, consultants, contractors, sub-contractors, etc.) can impair innovation. Although the main contractor is responsible for the assembly of components and integration of systems (Reichstein et al., 2005), component suppliers often are the main source of innovation (Mahapatra and Gustavsson, 2008). Hence, problems arise in the coordination of innovations at the component and system levels. The construction and operation of buildings is normally done by different actors, reducing the incentives to optimise the building design over the entire life-cycle.

The long life span of buildings (at least 50 years) makes it difficult to provide evaluations of new concepts. Hence, perceived risk, failure, repair and modification lead to a conservative nature which slows the innovation process (Mahapatra and Gustavsson, 2008), and thus, slow diffusion of new approaches e.g. related to multi-storey wood construction.

As regards basic materials for construction, concrete is the prevailing structural material in the multi-storey construction market in Finland and Sweden. For example in Finland, the share of concrete as a material for frames in multi-storey buildings was 95% in 2015, whereas the share of wood was only three percent (Statistics Finland 2016a). In single-family houses, however, the share of wood was 84%. The use of concrete in the multi-storey segment is deeply rooted in the construction regime, from the various actors in the education system and professional expertise to the efficient and industrialized material supply chain, and the prevailing views on fire-safety.

5.3 Multi-storey wooden construction in Finland and Sweden

The history of multi-storey wood construction in Finland and Sweden shows that fire-safety has played a dominant role in the development of the business. For example in Sweden, a ban for wood buildings exceeding two floors existed from 1874 until 1995. The ban was due to the multiple severe fires experienced in Swedish cities. During that period, the construction system based on non-wood frames (brick or concrete) developed due to the support of institutions, growth of actor networks, and investments in machinery, human resources and technology development (Mahapatra et al. 2012). The Finnish and Swedish national building codes were adapted to the construction product directive by introducing functional requirements when the countries joined the EU in 1995 (Boverket 2006). Fire safety was still a prioritised issue, but it was the builders' responsibility to demonstrate compliance with the requirements. However, fire safety is not a regulatory or technical barrier in multi-storey wood construction any more. In addition to structural fire protection, wooden buildings can be equipped with automatic extinguishing systems using sprinklers. The most popular type of system for wooden buildings is high-pressure water mist sprinkling (Puuinfo 2016). Nevertheless, it takes time to correct the preconceptions of less fire-safe wood buildings at the market.

Since 1990s, public policy and research action has supported multi-storey wood construction. For example in Finland, a variety of government policy programmes and action plans have promoted timber construction (Natural Resources Institute 2011). These include: Wood Construction 2000; Wood in Construction Technology Programme 1995–1998 – action programme; Year of Wood 1996; Time/Era of Wood 1997–2000 Campaign; Wood Europe Wood Finland 1998–2005; Programme for Promotion of Wood Construction 2004–2010 (Aarne et al., 2005). In Finland, there has been criticism of an entrenched unwillingness to allocate resources to developing wood knowledge, including education (Heino 2011). Some of our interviewees mention that Sweden also shares this need to educate skilled work force in wood building.

A background document for a national strategy for wood buildings in Sweden concluded in 2004 to derive academic R&D on wood buildings primarily focusing on the material properties of wood. However, only a few institutions conducted research on wood building production and business development. The industry research institute Trätek was among the pioneers in building new knowledge in wood-building technology, but an evaluation of its activities between 1996 and 2002 showed that projects on wood building were largely missing. There were some successful projects on fire safety issues but knowledge and information dissemination to potential customers, developers, and consultants was largely missing. (Näringsdepartementet 2004)

The environmental properties related to climate objectives are an important and obviously positive aspect of wood buildings. The strategy background document mentioned above reported that further research should prioritise robust methods for calculating the environmental properties of different materials in the development of industrialised building processes with wood as a suitable base. Moreover, the report concluded that the research funding for wood buildings was just a fraction of the public support to R&D in the forest industry (ibid).

In conjugation to the national strategy, several Swedish municipalities adopted local wood building strategies. Växjö was among the pioneers; see The Växjö case text below.

The Växjö case

The first wood building strategy in Växjö was launched as a local version of the national strategy in 2005 and was followed up by a planning programme in 2006. Since then, the strategy has been revised and new plans been added. The present strategy "the modern wooden city" was approved in 2013. It is seen as a component in building the "greenest city in Europe" (Växjö 2013). The current strategy has the targets that 25% of new buildings built by the municipality and its companies should be wood-based by 2015 (44% was achieved) and 50% by 2020. The strategy is a success, and wood building has become more of common practice (Hans André, personal communication). The municipal wood building strategy connects to the overall environmental programme of the municipality for a sustainable and fossil free future. The programme has the aim to contribute to sustainable local development. The rationale for the strategy is that Växjö is located in a forest region. The aim is to promote the use of wood in new building projects, not only for the municipal actors but also for all other actors in wood and construction industries.

There is a political consensus in investing in wood buildings, and Växjö should do it in collaboration with business, industry, and academia as a triple-helix formation. Thus, an additional component is to build regional competence in wood building[13], foster entrepreneurship and business development. Another actor in the collaboration is the Linnæus University that conduct research on technical aspects of wood building as well as life cycle assessment and climate aspects. Moreover, the university offers training courses for professionals from the industry. Växjö also hosts an annual dialogue conference for municipalities, businesses and actors of various backgrounds meet to develop ideas on quality and sustainability in wood building.

In addition to national strategies, policy programmes and action plans, multi-storey wood construction support includes implementation of large pioneering wood building projects. For example in Sweden, the housing exhibition Bo01 demonstrated large wood conceptual buildings in Malmö already in 2001. Vinnova contributed to funding of technical development of one of these buildings. The latest showcases for multi-storey wood construction in Finland include the biggest wooden residential building in Europe built up for the Finnish Housing Fair in Vantaa in 2015 and the Wood City project in the centre of Helsinki projected to complete by 2019.

Despite all support efforts, the market share of wood in multi-storey buildings has remained on a modest level. In general, the use of wood as a building material differs vastly with respect to building type. In Finland, wood comprises approximately 40% of all building materials, with almost 90% of detached housing and nearly 100% of leisure homes having wooden structural frames and cladding (Metla 2012). Small-scale housing traditionally favours wood as construction material. In practice, it would be difficult to increase the use of wood in small-scale home building projects in Finland (Puuinfo 2016). The situation in Sweden is similar with a market share for wood of 80-90% in detached housing. Since 1990s, the share of large buildings with wood frames has increased and reached about 10% of all large buildings in Sweden (see Table 13).

Table 13. Newly built flats in Sweden (TMF 2016).

Year	2007	2008	2009	2010	2011	2012	2013	2014
Total amount of new flats	16 310	9 019	6 961	12 127	13 398	12 520	16 951	19 216
No of flats in buildings with wood frame	1 190	983	859	1 047	882	1 267	1 711	1 691
Share of wood frame of total, %	7.3	10.9	12.3	8.6	6.6	10.1	10.1	8.8

The number of high-rise wood buildings in Finland is still relatively small. The database by Ministry of Employment and the Economy and Puuinfo listed all the Finnish high-rise wood-building projects (either planned or under construction). It consisted of 55 projects throughout the country in 2015 (Figure 8). The total amount of completed wood building projects with more than two floors was 27 (Puuinfo 2016). The market for high-rise wood buildings clearly seems to be developing more slowly in Finland compared to Sweden. In Sweden, the market share of multi-storey wood buildings is around 10%[14] (Table 13). The number of high-rise wood buildings in Finland is still relatively small. The database by

[13] "Think Wood for a Sustainable Småland", Regional strategy for timber and wood-related industries, adopted by the three regional development councils in Småland in 2012

[14] Out of the about 20 000 dwellings built in 2014, 1 700 were built in wood. Concrete is the most common building material for multi-dwelling buildings. (TMF 2016). In addition to these, about 1 000 smaller flats, such as student houses, were built from wood but not included in the statistics on wood building (Yvonne Identeg, TMF, personal communication 20160902). The share of wood has been fluctuating around 10% for several years.

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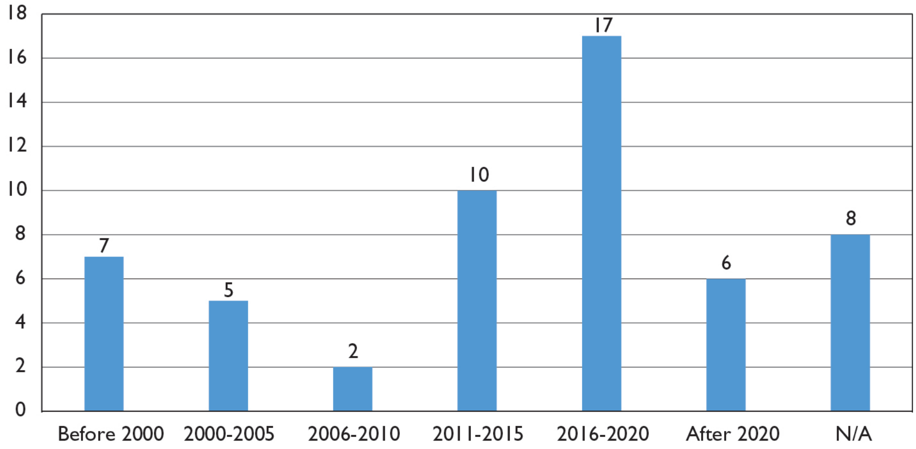

Figure 8. Multi-storey wood construction projects in Finland by year of completion.

The expectations for market growth for multi-storey wood buildings are high in Finland and Sweden, despite of a slow start especially in Finland. The goal of the Finnish government's strategic wood construction programme was about 10% market share of multi-storey wood buildings by 2015. Thus, the number of new flats in multi-storey wood buildings should have been approximately 1700 per year in 2014-2015. In reality in that time, the market share of homes in multi-storey wood buildings was less than one percent (Woodarchitecture.fi 2016, Confederation of Finnish Construction Industries RT 2016; Statistics Finland 2016b). Of the estimated area of high-rise wood building projects, planned or under construction, approximately 80% was for residential and 20% for office and retail purposes. The amount of apartments in these projects is estimated at 6800, which is a small fragment of the total 2 866 000 homes in Finland. Towards the end of 2010s, the number of new building projects was clearly growing.

In Sweden, the production capacity is continuing upwards and the current (2016) prediction on new orders implies an increase of 40% compared to 2015 (TMF 2016). It is noteworthy that construction in the 3-6 stories segment is not fundamentally different from 1-2 stories from a construction point of view, hence a significantly increased share for wood-based construction is technically, and given appropriate conditions also economically, feasible.

Outside Scandinavia, the markets for wood building are generally less developed. On the other hand, the markets for multi-storey wood frame buildings seem to have developed favourably in specific regions of the world, e.g. Austria, Germany and Switzerland. However, data on the total share of wood frame buildings (including multi-storey and public buildings) in Europe is not comprehensively availa-

[15] Out of the about 20 000 dwellings built in 2014, 1 700 were built in wood. Concrete is the most common building material for multi-dwelling buildings. (TMF 2016). In addition to these, about 1 000 smaller flats, such as student houses, were built from wood but not included in the statistics on wood building (Yvonne Identeg, TMF, personal communication 20160902). The share of wood has been fluctuating around 10% for several years.

ble (Manninen 2014). In Germany, about 2% of new multi-family houses were with wood frames annually over the beginning of 2000s (Mahapatra et al 2012).

The availability of raw material might form a barrier for continuous growth in wood construction. In practice however, wood used for large buildings in Finland and Sweden is currently just a fraction of the domestic consumption of sawn timber. The annual production of sawn wood is in the order of 10.6 million cubic meters in Finland and 16 million cubic meters in Sweden; of which approximately five million cubic meters in Sweden and two million cubic meters in Finland are used domestically. A conservative estimate gives at hand that less than 0.2 million cubic meters is for large wood building in Sweden; considering the fact that the multi-storey wood construction projects are less common, the amount of wood used for this purpose would also be smaller in Finland. In total, buildings made of concrete use more of wood for doors, windows, panels etc. due to a substantially larger market share. The production of glulam beams uses wood to similar level as large wood buildings in Sweden, and the glulam production seem to be only slightly bigger in Finland. It appears that a growth of industrialised production of larger wood-based buildings would not substantially influence the availability of raw material in a medium-term perspective. In Finland, a recent estimation showed that even if all the current multi-storey apartment production would use CLT, with the present forest growth Finland would need only 14 hours to produce this demand (Helenius 2016). As mentioned above, it would be difficult to increase the use of wood in small-scale home building projects in Finland and Sweden. Consequently, the availability of raw material is very unlikely to form a challenge for multi-storey wood construction during the next few decades.

5.3.1 Key actors

As regards industry structure, two industries (regimes) related to the construction of wood buildings can be identified. Firstly, the forest product sector, that includes sawmills and the building element industry, are looking to boost their product offerings in the construction sector in part due to the structural decline of the forest products industry. Secondly, several groups or types of actors that are involved in the construction projects and related investing, design, planning, maintenance and reuse of buildings.

The forest products for construction use

There are three main types of actors serving wood construction as suppliers of wood-based materials, elements and building modules: 1) producers of basic materials, 2) manufacturers of building elements and prefabricated modules for wood houses, and 3) building supplies traders. The first two actor groups focus on wood materials, whereas the third actor group typically trades in construction materials other than wood. According to the extensive national database of woodproducts.fi, which consists of Finnish wood construction material suppliers that are members of the associations behind the Puuinfo (in English woodproducts.fi) network, the total number of actors in the business of forest products for construction use was well above 100 in Finland in the end of 2016. Fifty of these companies were producing basic materials (timber and panels), and 36 companies supplied more refined products, namely panels and modules. Most of the companies supplying wood materials for construction are SMEs typically with 10-50 employees, and despite this, exports played a significant role for many of these actors.

In 2016, Stora Enso launched the first building system for multi-storey residential buildings based on massive wood elements and housing modules with CLT technology. Even if forest industry actors' offerings are currently dominated by further processing of sawn timber and single family tailored wood buildings, some actors in Finland already seem to offer prefabricated solutions for multi-storey wood buildings as well (Table 14). In Sweden, this segment is a thriving and well-established business.

The data provided by Puuinfo (2016) on completed and planned multi-storey wood construction projects in Finland is limited in terms of material suppliers. Stora Enso, with its CLT based modular multi-storey concept seemed to have a leading role in the growing market of materials for multi-storey wood construction in the 2010s. Stora Enso was involved in more than half of the Finnish projects with relevant supplier data. The other suppliers involved in Finnish projects in the 2010s include only one or two projects in their references. Thus, in Finland there is one major actor dominating the market while in Sweden there are several smaller (and growing) companies that dominate the market.

Table 14 .Examples of relevant business actors for multi-storey wood construction in Finland and Sweden. All these actors are on commercial stage.

Activity	Actor	Products	Comments
Forest	Crosslam Kuhmo	Cross-laminated timber (CLT) panels and elements	The first (and only) CLT manufacturer in Finland in 2017
Forest	Kontiotuote (part of PRT group)	Loghouses (leading producer in Finland)	References include Lillehammer Olympic Village and Pudasjärvi School Campus (2016)
Forest	Lappwall	Prefabricated LEKO® wood elements and components	References include DB Schenker's giant road transport terminal near Helsinki Airport (2015)
Forest	Metsä Wood	Laminated veneer lumber (Kerto® LVL) and other engineered wood products	Used in all types of construction projects from new multi-storey buildings to renovation and repair
Forest	PRT (Pyhännän rakennustuote)	PRT-Pro™ wood element solutions for large buildings	PRT acquired Hartola plant from Stora Enso in 2016
Forest	Stora Enso	Cross-laminated timber (CLT)	Stora Enso is the biggest CLT producer in the world; no production in Finland
Forest	Stora Enso	CLT and LVL-based modular multi-storey building systems with flexible spaces	Manuals available for construction and design professionals; reference Wood City in Helsinki (2017-19)
Forest	Versowood	Glulaminated timber	Metsä Wood sold its gluelam beam business in Hartola to Versowood in 2016
Construction	Reponen	Implementation of several multi-storey wood building projects in Southern Finland	References include the biggest wooden residential building in Europe (2015)
Construction	SRV	Multi-storey modular wood building projects	Hotels and offices in addition to housing at Wood City in Helsinki (2017-19)
Forest	Organowood	Eco-friendly wood and wood protection	Applications in smaller scale construction projects
Construction	BoKlok	BoKlok concept	Applications available also in Finland
Construction	Martinson	Glulam & CLT. Elements	Based in sawmill with their own R&D.
Construction	Lindbäcks bygg	Modules & element.	New production facility for industrialised construction.
Construction	Moelven	CLT, Glulam, modules	One of the leading producers
Construction	Derome	Glulam, elements	Expansive. Developed from sawmill. Bought eg plus-houses from Setra.
Real estate	Folkhem	Developer	Developers specialized in wood construction. In collaboration with Martinson.
Construction	Setra	Glulam	Wood components
Construction, Real estate	K2A fastigheter	Developer	Construction and real estate
Construction	Skanska	Contractor	Mainstream builders. Occasionally using wood frames
Construction	NCC	Contractor	Mainstream builders. Occasionally using wood frames

Construction and maintenance of wood buildings

Along with the rise of circular economy approaches, specialists for real estate recovery, reuse, and refurbishment of buildings are likely to have a bigger role in the future. Coordinators and regulators of the reuse of old buildings as well as the specialists in demolition, recycling and utilisation of materials in value chains will continue in the construction and reuse actor network.

A few incumbents dominate the overall multi-storey construction market in Finland and Sweden. For example, NCC, PEAB and Skanska have spread their businesses all over Sweden and Finland. However, the incumbents play a considerably smaller role in wood construction than could be expected from their company size. During the first years of multi-storey wood construction in the late 1990s and in the beginning of the Millennium, there were predominantly smaller companies involved. With a few exceptions, incumbents in the industry seem to have activated only during the last few years. Most of the construction actors in the Finnish dataset (Puuinfo 2016) have only worked on one or two multi-storey wood building projects, which poses challenges to learning and systematic knowledge development and diffusion. Consequently, most of the projects served as experiments for these actors.

In Finland, one construction actor had clearly started to develop a business strategy based on multi-storey wood building. Reponen, a SME construction company, stood out as the most prominent example of business with a focus on high-rise wood buildings. Among the several multi-storey wood building projects completed by Reponen is the biggest wooden residential building in Europe, which was finalised for the Finnish Housing Fair in 2015.

Many of the big construction sector actors are also involved in the development projects with their own specialists. Real estate investors join in the green field (new buildings) and brownfield (reuse) projects typically before they are completed, and continue their commitment during the use phase of a building. However, none of these actors has a specific interest in wood as a construction material compared. Economic reasoning is the basis for any project evaluation and promotion rather than material choice. Instead of private sector actors, municipalities and their affiliates, such as public subsidised housing services, have often taken initiative in recent wood construction projects in Finland and Sweden. Thus, in addition to city planning and regulation, public actors can promote wood construction through procurement.

In the planning phase of a construction or renovation project, architects, designers and other specialists are central actors. As regards multi-storey wood buildings, we could identify 50 actively involved architect agencies or other design and planning actors in the data from Finland (Puuinfo 2016). Here again, most of the actors had references from only one or two projects in the dataset. Interestingly, the most active actors changed from the years of the first little boom of wood construction in the late 1990s by the next growth period in Finland in the 2010s. Bigger actors, such as Finnmap and Sweco replaced the small pioneers of the 1990s.

There is a link from wood building design and construction to education and research actors. In order to be able to scale up design and construction of multi-storey wood buildings, expertise and knowledge development should take place and be secured through research and education activities. However, the scope and depth of education and research may not be sufficient to face this challenge, for example in Finland, without additional coordination and development inputs (Heino 2011). As mentioned above, national coordination and regulatory actors have launched development programmes aiming at better opportunities for wood construction. As regards building regulations, Finland and Sweden follow harmonized EU legislations on wood and wood products.

5.3.2 Landscape

A number of significant general trends potentially influence the multi-storey wood construction segment. First, the market volumes in construction, in general, are rising with population growth, urbanisation and frequent re-settlements of the population. At the same time, construction markets increasingly become international and even globalized. The climate impact of housing and construction also create pressure to invent new climate friendly actions. Resource constraints drive energy and material efficiency. Due to the 'sick building syndrome' and the problems with air circulation and damp linked to the need to renovate the building stock, health issues and reduced chemical risk for the users of homes and offices drive renovation and re-use of buildings. Production systems become industrialised with automation and digitalisation as key enablers. New developments in materials (e.g. innovations in wood-based elements and structures, such as cross-laminated timber, glued laminated timber, and building modules) support this development. Congestion in transport systems drives lean logistics and rapid construction. The decline and restructuring of international forest product business in the newsprint and printing paper segments increase interest in other bio-based products, including wood construction materials.

5.3.3 The multi-storey wood construction niche

There is a drive for development within the multi-storey wood construction niche. As seen from the Nordic perspective, it has a number of key characteristics. There is volume growth, first in Sweden and, starting in the 2010s, and more recently in Finland. However, the market is mainly populated by domestic actors with some exceptions of actors working internationally. The market for multi-storey wood construction is overall not very competitive in Sweden and Finland. The incumbents of the construction industry are passive. The activity comes mainly in form of SMEs specialised in wood construction, and often with an origin in forest industry. Islands of wood thinking in early phases of development projects already exist. For example, municipalities and developers promote wood construction for a certain area or building from start.

The production of wood-based frames is increasingly industrialised, giving both cost and environmental improvements for wood construction. Standardisation of products and methods is a core support for this development. Wood-based frames enable new applications, e.g. add-ons to existing buildings allowing for densification and value-addition. CLT as an innovation supports the trend towards industrialised production. Flat-packed and (partly) prefabricated wooden construction methods, using CLT, are well positioned to cater for growing international markets in sites where logistics and construction time is a constraint, e.g. in mega-cities. Modularisation, which couples to industrialisation, is a development that supports growth of the segment.

Uncertainties exist among actors in the value chain of wood-based construction. The building code is set for concrete, the prevailing paradigm in multi-storey construction in both Finland and Sweden, and uncertainty of how it will evolve may hinder investments in standardised and industrialised production. The knowledge and experience base on prefabricated wood building processes among technical consultants and architects is weak. The environmental case for wood-based construction is unclear among some actors in the value network, even if it is obvious from the experts' view. Embedded carbon, renewable material, and local or domestic sourcing of wood, frequent the environmental claims of multi-storey wood buildings. Environmental assessments do not recognise the value of embedded carbon, but there is a resolution in sight.

Maintenance of facades and the longevity of the building stand out as concerns for wood buildings. In terms of quality, acoustics and post-fire value concern the potential users. Perceived fear of loss of aesthetical values from standardised prefabricated buildings exists as well. Experiments with customer adaptation of standard modules will abate concern.

5.3.4 Drivers and barriers

Several trends from the landscape level potentially influence the multi-storey wood construction segment as drivers. Regime dynamics also reflects these pressures, along with many other drivers. In addition, the characteristics of innovations have potential to promote wood building. The market potential seems favourable and several environmental and social arguments speak in favour of wood construction.

Despite all promotion with positive arguments and assessment efforts, the results at the construction market look still rather poor. Naturally, there have been many critical counter arguments and the traditions as well as competition by suppliers of other materials have often resulted lock-in.

Drivers

Satisfying housing needs in a world with growing and increasingly mobile population are among the most significant landscape level pressures on multi-storey construction. A need for quicker construction is evident. Expectations for more environmentally friendly and energy efficient building materials and construction processes are rising as well. Due to the structural changes in the economy and society in Finland and Sweden, the desire for new jobs in rural areas drive entrepreneurship and growth based on bio-economy, including refined wood products for construction.

Wood has a highly positive reputation. As a building material, wood is environmentally friendly, and consumer attitudes, interest and preferences are favourable for wood. In the socio-political environment, municipalities, city planning and public housing services have shown growing interest in promoting wood construction. Prominent local showcases of large-scale wood construction like Lahti in Finland and Växjö in Sweden already exist. Additionally, individuals who believe in the cause and promote wood construction technology have stood out, forming socio-political environment more favourable for wood. There is also a wish for differentiation and more value adding products in timber industry. Wood products are an economically significant part of forest sector, underlining the co-evolution of the forest and construction sectors. As regards the Nordic forest industries, the wood products for construction and interior design are one of the potential and natural strategic future growth areas for the sector, and the national economy as well. In Finland, the Finnish timber council has pushed forward a reform of wood construction regulations, especially linked to fire-safety, which has activated SMEs in the wood product sector.

As for techno-scientific knowledge dimension of the regime, willingness to develop knowhow and business on wood construction exist (e.g. Haapio 2013, Heino 2011). For example in Finland, an update of training on all levels of education to meet the demand in wood construction business was included in the national wood construction programme (2011-2015). National level policy programmes and action plans include considerable increases in the market share of multi-storey wood buildings, putting pressure on the actors. The core firms in the producer network are facing pressure from other actor groups which are responding to landscape pressures, some of which are prominent in the forestry sector.

Availability of timber as well as possibility to increase harvested volumes sustainably in Finland and Sweden are potential drivers of multi-storey wood construction as well. As a response to major landscape pressures, wood buildings show ecological sustainability (renewable material, low carbon intensity, availability in the Nordic countries etc.) and energy-efficiency. Thus, wood construction already is a response to potentially stricter ecological sustainability regulations. The economic sustainability of wood construction is a potential driver as well. Innovation characteristics of wood construction include reduction of building time up to 50-70% compared to traditional concrete elements. In addition, the modules are not exposed to weather conditions, CLT has space-saving potential (external and internal walls are thinner, meaning 6-10% more living space in a house made of CLT). Thus, new technologies have increased the cost-effectiveness of wood buildings. Hybrid solutions combining different raw materials effectively and unconventionally in buildings are potential drivers of wood construction in the future. There is effort to develop the whole construction process and chain of services instead of developing mere end-product. On the other hand, an underdeveloped supply and service chain may also prove to be a barrier (see below).

Barriers

As for *industry structure*, one of the most important barriers is the strong concrete tradition and lower cost-efficiency of wood materials. From construction point of view, the regime of design and project implementation is adapted to concrete and steel e.g. due to efficient existing supply chains of these materials compared to wood materials supply. Path dependency related to expertise, traditions, etc. also explain part of the unwillingness of incumbents to engage with alternative materials and technologies. Less developed standardization of wood building materials and generally limited lifecycle-thinking in construction this far are likely to counteract the strengths of wood use.

As regards *technology*, other building materials are normally and frequently necessary also in wood buildings. This hybrid use of materials may be both a barrier and an opportunity. For example in Finland, other materials are not import goods either, and even if they might not be renewable, they are at least to some extent recycled as well. Consequently, competitors seem to question the environmental friendliness of wood.

When it comes to *techno-scientific knowledge*, lost knowhow and culture of wood construction may turn out to become a barrier. For example, Austrian architect Kaufmann has said that “The Finns have lost touch in the tradition of wood building” (woodarchitecture.fi 2016).

From *user practices and user markets* perspective, the value added and competitiveness of wood as a construction material over the lifecycle of a building has to be assessed for each case. Several factors influence which material will be most favourable. There is, however, an expectation among real estate actors that standardised and industrialised produced buildings will both lower the costs and decrease construction time.

The analysis and deeper understanding of user needs is largely missing. Thus, the suppliers have not been willing to elaborate much their existing business models. Until recently, the supply and services related to wood-based construction material for high-rise buildings has been underdeveloped.

In terms of *cultural and symbolic* regime dimension, mind-sets and resistance may prove barriers to growth. Negative attitudes to wood as a construction material exist in terms of fire-safety, durability and maintenance.

Even if municipalities, city planning and public subsidised housing services have shown growing interest in promoting wood construction, *sectoral policy* may also prove to be a barrier to wood construction. Local decisions concerning construction materials may hinder the use of wood. As regards circular economy, planning of land use and respective regulation may block the reuse of e.g. unoccupied office buildings as well.

5.4 Circular approaches in wood construction in Finland and Sweden

The concept of the circular economy is already familiar to the construction industry. However, the actual meaning of the concept looks still undefined. Advances in production efficiency emphasize recycling with environmental objectives such as minimisation of production waste (both overall and at the construction site), re-use of spills or incorporation of fractions that otherwise would not be useable. In terms of real estate business, it might be related to, for example, more efficient reutilisation of industrial and office buildings when they become empty. Currently, there is a danger that the circular economy becomes a buzzword without real meaning and business value. However, circularity aspects are traditionally inside wood construction: for example, rebuilding from used logs exists, and Rakennusapteekki is good example of small businesses developing and providing eco-friendly tailored supplies for the recovery of old wood buildings in Finland.

5.4.1 Construction and real estate business actors in circular economy

When considering the construction sector and (wood) buildings, the different views between the real estate business and the construction business should be kept in mind. Property or real estate development refers to the repurposing of premises, or their enhancement, often through new or renovation construction. Real estate business focuses on financial process related to developing and ownership, whereas construction business traditionally focuses more on the material process during the implementation of building projects. In some cases these two business approaches overlap; e.g. Skanska in residential buildings and SRV in office buildings and shopping centres in Finland.

The timeframe of decision-making is also different. Real estate businesses are more concerned about the impacts (and profitability) throughout the lifecycle of buildings, whereas construction firms are mainly concerned about the performance during construction phase. However, the sustainability of any building should be considered throughout its lifecycle, including demolition and material end-of-life phases.

Key actors during the lifecycle of buildings include investors, planners and designers, developers and constructors, users and occupiers (of buildings for different purposes: residential, office, retail, industrial and leisure), facility management, and finally demolition and recycling specialists. As the concept of the circular economy becomes more commonplace in the society, it is likely to strengthen the role of specialists for maintenance (preservation) of buildings, and especially specialists for real estate recovery, reuse and refurbishment of buildings. Property developers and real estate investors are already involved in this kind of activity through repurposing of premises, and facility management services have a role in the preservation of buildings. For example, L&T is the biggest provider of a variety of necessary services to maintain property in Finland. Renor and Consti are examples of actors in the field of reuse of buildings, but it is difficult to find specialisation in wood buildings here.

When a building has come to the end of its lifecycle, demolition, recycling, or utilisation in another value chain becomes necessary. In Finland for example, recycling and demolition specialist Talosiirto focuses on concrete recycling from demolished buildings, but wood and metal materials are recycled as well. International research projects, such as HISER (Holistic Innovative Solutions for an Efficient Recycling and Recovery of Valuable Raw Materials from Complex Construction and Demolition Waste), strive to develop and demonstrate cost-effective holistic solutions (technological and non-technological) for a higher recovery of raw materials from ever more complex construction and demolition waste (C&DW). As regards utilization in other value chains, and incineration of construction waste, specific treatment is necessary for impregnated wood. In Finland, Demolite has taken responsibility for the recycling of impregnated wood with a network of recycling points throughout the country.

5.4.2 Drivers and barriers for circular economy in construction and real estate business

Certain societal megatrends are very likely to promote the circular economy in the businesses. For example, more renovation projects and more brownfield investments (i.e. reuse of old industrial and office buildings) instead of green field investments (the traditional approach) are to be expected. Rising awareness of sustainability in the finance sector is likely to promote not only the circular economy, but also other sustainability related factors in the real estate business and construction sector.

According to our expert interviews, the critical factors that seem to limit or slow down the adoption of circular economy approaches in real estate and construction businesses can be many and they relate to e.g. regulation, market and society. In terms of regulation, inflexible city planning often limits the reuse of old buildings; examples of experiment platforms that give free hands to developers are rare. As regards the market, the unawareness and conventional mind-set in the industry regime might slow down the transition towards more lifecycle and circular oriented approach.

Reuse of buildings, recyclability, design for reuse, and energy use (incineration) at the end-of-life may prove challenging due to chemicals, paints and other treatments in the wood material. However, the prevailing approach does not consider re-use or re-cycling in new building projects. This holds true also for large wood buildings. In order to promote circularity, the forest and construction industries should look for new wood treatment methods based on alternative preservatives in the future. On the other hand, wood being suitable for energy recovery might further dis-incentivise design for reuse and recycling.

Generally, green building certification programs and rating systems (e.g. Leadership in Energy and Environmental Design LEED, Building Research Establishment Environmental Assessment Methodology BREEAM, and national scheme operators) offer certain credit for the use of wood or wood products. Credits are available for third-party certified wood materials, as well as local materials, but also for products with recycled or reused content. Many rating systems also reward for the use of lower quantities of building materials and avoiding construction waste.

The competition from other construction materials—mainly concrete, but also steel—with their recycling schemes will continue to challenge the wood construction also in the circular economy. For example, there has been intensive research activity to improve application of recycled aggregates in concrete mixtures without affecting the final properties of concrete.

As for the society, houses are normally designed and built to last ”forever”, instead of building for a clearly limited time (e.g. 20 years), so that they could also be easily reused or recycled in the end of their estimated lifecycle. Alternative lifetime perspectives aiming at limited temporary use and increased circularity already materialise in single construction projects and concepts (cf. prof. Junnila).

5.4.3 Potential for circular ecosystems in wood construction

The development of circular innovation ecosystems for wood construction, from maintenance to reuse, remaking, recycling, and utilization in another value chain, is far from complete in Finland and in Sweden. The construction and real estate sector is aware of the challenges regarding circularity aspects, and examples are available, but the sectors do not yet have a formulated strategy available. As mentioned above, the design and construction of buildings generally aim at houses that would last for at least 50 years. This plays down the relevance of designing for decommissioning. In Sweden for example, a Vinnova funded project including IVL and Vasakronan explored opportunities to taking out components for re-use in renovation projects (IVL 2016).

Pre-fabricated wood frames and modules can complement old buildings as add-on or attachments in renovation projects to enlarge or make the old buildings suitable for other purposes. The wood systems have the advantage of lightweight, which makes it possible to add floors onto existing concrete building frames. From a circular economy perspective, the add-on wood structures prolong or change the use of the existing structures. The enlargement of a building could also add to the financial viability of a renovation project.

There are examples of pre-fabricated disassembled buildings moved to other places. Modular temporary building sector demonstrates an interesting example of reuse both in Finland and in Sweden. Industrially produced wooden modules connect into different shapes for various functions, such as temporary homes, schools, day care centres up to four floors without supporting frames. Modern temporary modules are prepared for connection to district heating, water and electricity, and perform according to the building code. These modular buildings have aesthetically left the simple bunkhouse style. The companies that offer the modules, for instance PCS Modulsystem, Expania, Temporent, Flexator, lease them out with different levels of attached services to the tenants. After the lease, the modules are disassembled and moved to another place. The main hurdle for expanding the business is, according to Attefors (personal communication, see appendix 1), a fear of uniform design and difficulties to get temporary building permits in Swedish municipalities. Temporary homes is still a market niche of its own in Sweden, the systems have though a history as supplementary school buildings, etc. According to Atterfors, the system is more used for temporary homes in Norway.[16] The wood product manufacturing com-

[16] For illustration see: http://bygg-pro.no/portfolio-items/brakkerigg-avinor/

pany Moelven, among others, produce such modules for temporary buildings. In Finland, Crosslam Kuhmo and Lapwall were among the first element and module manufacturers.

New wood treatment methods based on alternative preservatives or structural changes of the cellulose fibres is offered by for instance OrganoWood with major production in Nybro. The products can replace conventionally preserved wood and thus contribute to decrease the use of toxic substances, which is one objective in the circular economy. In Sweden only, about 1 million cubic meters, and in Finland, 0.3 million cubic meters of wood is preserved annually.

5.5 Development of multi-storey wooden construction towards circular bioeconomy

5.5.1 Development potential for exports of materials and knowhow

As mentioned above, the wood construction case sits within the forest product sector that includes wood material suppliers, such as sawmills and the building component industry. The forest products sector wants to boost their product offerings to the construction sector due to the structural decline of the forest industry. Secondly, we can identify several groups or types of actors that are involved and interlinked in construction projects and/or related design, planning, investment, use, maintenance and reuse of buildings. Additionally, several factors can reshape the traditional business models of these actors and construction and real estate business models towards a more circular bioeconomy. Product innovations in wood materials, such as CLT, can contribute to increased prefabrication and modularity in multi-storey wood building projects. This in turn can reshape the construction processes towards more industrial production. Modularity, together with environmentally sound materials avoiding e.g. certain chemical treatments in the wood material can increase user orientation in the construction sector, as well as improve modification, reuse and recycling in alternative uses of wood buildings (Figure 9).

There is high potential for wood construction materials and novel business models in Finland and Sweden. As discussed above, the drivers for wood construction are many, ranging from the availability of timber resources, to eco-friendly and energy efficient materials and processes, to strong national will to develop the sector. Furthermore, relevant technical innovations like CLT already exist. More cooperation between actors along the building value chain could tackle the many barriers to the growth for circular wood construction; from raw material and building element production to users, maintenance and reuse actors.

Despite of the long traditions and large share of wood building in Scandinavia and less developed know-how and markets elsewhere (except for parts of North America as well as Japan and Scotland), recent international examples of high-rise (12-24 floor) wood building projects originate from Austria and Canada. In Canada, wood has almost replaced concrete as building material in five-floor or lower buildings (Sihvonen 2015). Exports from Finland consist mainly of sawn and refined timber and single-family house solutions. In Sweden, export of multi-store buildings so far is mainly oriented toward the Danish and Norwegian markets. This is due to strong demand in the domestic (Swedish) market. As multi-storey wood construction and circular construction ecosystem develops and matures in Finland and Sweden, Nordic actors might find growth potential in selected export markets for wood buildings located in parts of Asia and Russia (Sihvonen 2015).

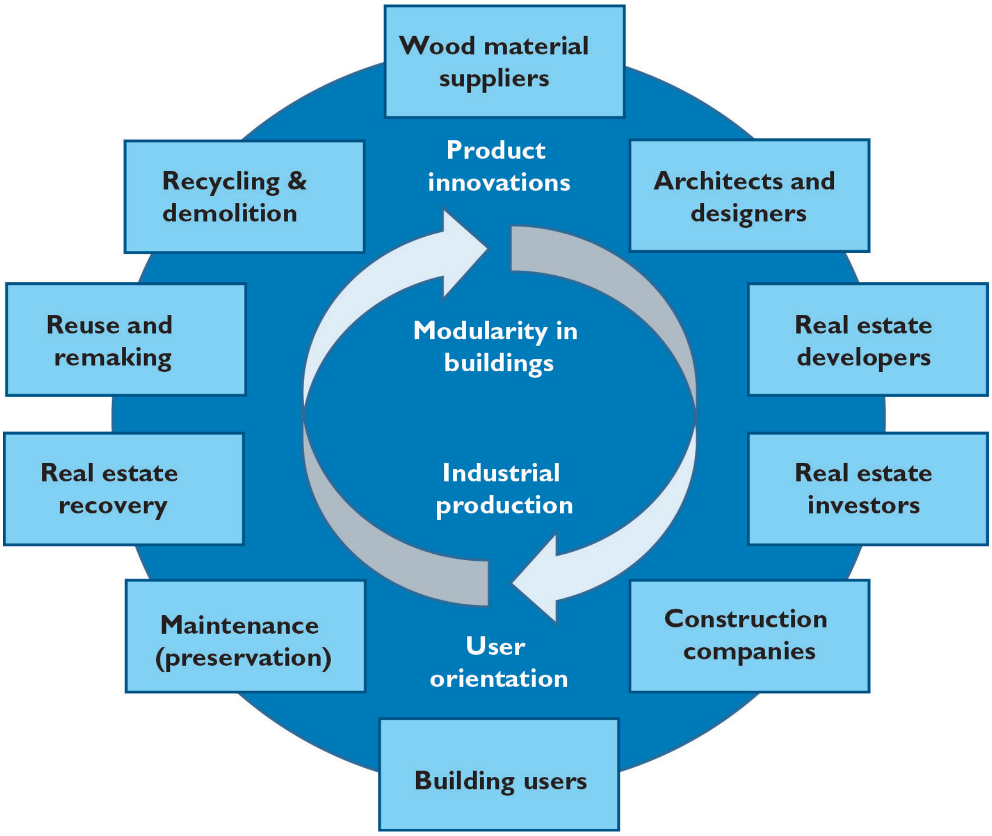

Figure 9. Actors and potential factors shaping business models for more circular multi-storey wood construction.

5.5.2 Future trends and development points

There are many potential strengths that could enable the development of a multi-storey wood construction ecosystem that can support circular material flows. Ecological benefits (renewable and recyclable raw material, smaller carbon footprint), and long traditions in wood construction are often mentioned, but technical benefits from prefabricated elements and modules, and reduced on-site construction times are important as well. In general, consumers have a very positive impression of wood buildings. Potential benefits for the users include acoustics, indoor air quality, aesthetics, etc. This forms a favourable background for the growth of multi-storey wood building market.

Despite good market and raw material potentials, the volume of business in high-rise wood building is still rather small in Sweden, and especially in Finland. There seems to be weak coordination between wood construction actors, and mainly random collaboration between actors in the value chain. In terms of circularity, construction business focuses on building projects (short term), whereas real estate business puts clearly more emphasis on reuse and life-cycle (long term) approach. Advantages of wood are often unclear for the majority of users and investors, and the investment cost for the user is higher, reflecting the challenges in the supply system of wood compared to other construction materials. The decentralised and experimental nature of planned and finalized building projects underlines the need for more systematic know-how and experience development. Low number of references from complete projects as well as a limited number of remarkable showcases projects result in lower credibility in wood construction business compared to concrete solutions.

At the moment, the need for industry renewal both in construction and forest sectors is an opportunity for actors in these sectors. This is also supported by political tailwind and specific development programs for bio-based business and circularity. The positive image of wood and the domestic renewable raw material base (availability) in Finland and Sweden are good opportunities as well. On the one hand, standardisation of products and solutions is likely to improve the efficiency of projects. On the other hand, construction and service solutions should include more flexibility and dynamic tailoring instead of inflexible, standardised offerings only. Public procurement and project initiatives have already shown their strength in multi-storey wood building projects in Finland and Sweden, and similar trend is very likely to continue. Collaboration instead of competition between actors producing different construction materials could facilitate the promotion of hybrid building solutions that combine different construction materials in one project. These hybrid material solutions, together with other value adding features for users could be included in buildings through more intensive collaboration with other industries, like ICT. In order to fully consider the circular economy aspects of buildings, more intensive collaboration between relevant actors along the value chain is likely to take place. This collaborative action could take place for example in the organization of systematic demonstration of modular, flexible and recyclable buildings.

Conservative attitudes and beliefs (e.g. fire safety) in the society, as well as unchanged mainstream course of action in the construction industry may prove discouraging to development and growth in the circular wood construction ecosystem in the future. Forgotten traditions in recycling and reuse of wood buildings in addition to lack of critical mass, significant project failures, water damages, etc. may erode the trust in wood construction anytime. Tough competition with other materials, especially concrete would certainly not facilitate from erosion of trust. On the other hand, concrete has recently also suffered from several trust eroding incidents related to raw material quality in large construction projects.

5.6 Potential environmental impacts of construction

Housing and buildings are among the main sources of global greenhouse gas emissions, resulting from all phases of the building lifecycle are important; including production of materials, the construction phase, the use phase (especially energy demands for heating, cooling and lighting) and end-of-life (Table 15). When constructing new buildings, the design of the construction, including the material and technology choices as well as their implementation, have direct and strong impacts on energy requirements of buildings, and their maintenance capabilities. Lifetime, modularity, reusability and overall environmental impacts of buildings are influenced by the type of construction materials as well.

Recent studies (including Larsson et al 2016, Boverket 2015, Gustavsson et al 2015, Dodoo et al 2016, SKL 2017)[17] point at a range of environmental advantages of wood as building material:

- its light weight: beneficial for transportation and construction site logistics, and light frames can be used in tall constructions.
- carbon storage: a building is expected to be used for 50 to 100 years. The carbon is stored during the lifetime.
- renewable nature of the material: in contrast to most other building materials.
- opportunities for industrial production: see below
- increasing importance of the carbon footprint of materials used: the construction phase is increasingly important and has come to be the dominating factor in a life cycle perspective before the use phase.

[17] In particular, the recent comparison of the two projects Blå Jungfrun and Standparken has been particularly helpful due to its thoroughness and transparency.

- opportunities to add on wooden structures in renovation and refurbishment projects: the light weight of wooden elements and modules make it possible to add floors and attach new area to buildings on to of existing structures.

However, it should be noted that buildings are never single material products; it is a matter of the balance between different materials and concrete is currently used for multi-storey wood buildings for foundations, basements, sometimes elevator shafts.

Wood as material is beneficial for industrial production of prefabricated elements and modules to be assembled at the construction site. The industrialisation of construction processes offers a number of environmental advantages such as:

- material efficiency: making use of low-grade wood, spill utilisation;
- waste reduction and recycling: design and production coordinated with input materials, improved opportunities to utilise wood waste for recycling when concentrated in a factory;
- modular construction enabling reuse: modules and elements could be reversely disassembled and assembled again. This is, however, not a common practice and experience is largely lacking;
- improved logistics: material logistics to and at the construction site protects the material and avoids losses;
- reduced risk of quality losses: indoor standardised production is commonly viewed as a guarantee for even quality. In addition, it gives better work environment.

Buildings are generally complex products with long lifetimes and, thus, it is difficult to assess and compare at the level of material choice. Typically, life cycle assessments have the disadvantage of being static whereas the development in the multi-storey wood buildings is highly dynamic including innovation raising the sustainability performance. Thus, it can be expected that the relative environmental performance of wood, when compared to steel and concrete, may be strengthened.

The conclusion is that there are no environmental or sustainability objections for using wood as building material given sourcing from sustainable forestry. At present, less than one percent of the sawn wood is a present used for multi-storey wood buildings in Finland and Sweden. On the contrary, a recent thorough and transparent study (Larsson et al. 2016) indicates a significant climate advantage to CLT frame in relation to concrete.

However, maintenance and care may imply environmental risks due to wood protecting substances. This, on the other hand, is also an opportunity for the promotion of innovative methods and materials, such as OrganoWood.

Table 15. Some of the most prevalent environmental impacts of construction (based on Judl et al. 2016, and the references therein).

Climate impacts, energy consumption and atmospheric emissions

Traditionally, 80-90% of the total energy use and CO_2 emissions in buildings are generated during the use phase. However, as buildings tend to be increasingly energy-efficient during use phase, embedded carbon in materials become more significant.

Fossil energy used in manufacturing, transportation, construction and the maintenance of buildings cause climate impacts. Cement in concrete buildings accounts for most of the CO_2 emissions. Concrete production is also an important source of particulates emissions.

Besides the use phase, the main source of atmospheric emissions in wood buildings is the use of fossil fuels in the manufacturing and transportation phases. While wood is chemically impregnated for certain applications to achieve durability, wood buildings act as carbon storage.

Resource depletion

Fossil fuel depletion caused by energy consumption during the use phase dominates the resource depletion category. The main issue related to resource depletion during the construction of buildings is the consumption of aggregates and other construction materials. Fossil fuels used in their acquisition and processing (e.g. cement manufacture), as well as during the construction phase, further add to the resource repletion. Wood is a renewable resource, but its sustainable production requires advanced forestry governance.

Water use

Water use does not represent a major issue in the construction sector in the Nordic countries as the water needed in the cement production is local and water scarcity is not usually an issue in Finland and Sweden. Moreover, boreal forests do not require irrigation.

Pollution

Potential use of chemically preserved wood may be a source of pollution. Moreover, at the end-of-life a large part of the chemically treated wood is classified as hazardous waste. Production and application of wood paints represents another potential source of pollution.

Land use

Illegal logging for valuable wood, deforestation and the conversion of pristine forest to plantations are globally serious land use issues that must be recognised as a risk in increasing the use of wood in buildings. Such concerns are largely absent in the Nordic countries.

Waste and recycling

In Finland, the construction business generates over 2 Mt of waste (excluding minerals), of which only a minor fraction is wood waste. In Sweden, the construction sector produces roughly one third of all waste in the country, and one quarter of the hazardous waste. The reuse of concrete waste can be difficult because of impurities and mixed materials. In conventional wood construction the amount of waste can be large and requires efficient collection and sorting for use in energy or recycling. Composite materials whether they are mix of wood and plastic or cement and plastic are generally hard to recycle and may become a problem in the end-of-life.

Chemicals used to impregnate to achieve durability of wood used e.g. as decking pose a serious environmental risk when such wood reaches the waste stream.

5.7 Relevant policies

The policy landscape around the multi-storey wooden construction innovation system (Table 16) was analysed using an analytical framework based on the TIS functions as explained in section 2.6.

There are a number of similarities in the emergence of multi-storey wooden frame construction in Finland and Sweden. Due to the slow pace of innovation and the conservative nature of the construction sector, sawmill actors rather than builders have been driving this emerging niche to develop new forestry product markets. Circular economy aspects have largely been neglected. Additionally, the fact that buildings are designed to last for decades has reduced the interest in their circular design. However, light pre-fabricated wooden add-ons demonstrate a great potential for remodelling old buildings for new functions and values.

5.7.1 Policies and actions supporting niche creation

Expectations and visions for wooden construction have primarily been driven by governmental programmes that have led the direction of search (C7). Actions promoting wooden construction have differed in terms of geographical coordination. In Finland, national level programmes, since the mid-1990s, have promoted wooden construction, whereas in Sweden, municipal (e.g. Växjö which has set a goal to build 50 % of all municipal buildings in wood by 2020 (Växjö kommun 2017)) and county co-ordinated programmes have been the main instruments.

Programme level initiatives have justified R&D activities leading to knowledge creation (C1) and the acceptance and legitimacy (C6) of multi-storey wooden buildings, especially in some municipalities in Sweden. However, there is still a lack of targeted and integrated policies in both countries—at the national, regional and municipal levels—and the progress that has been made is not readily sized upon by construction sector incumbents. A number of education initiatives on wooden architecture and design and structural engineering, and national and EU level R&D funding allocated to wooden construction projects are also contributing to knowledge creation (C1). Sectorial initiatives, in both countries, have also recently targeted knowledge diffusion (C1) and resource mobilization (C5).

Due to the lock-ins of concrete frame construction, the majority of the multi-storey wooden buildings have been initiated by either forestry sector actors through entrepreneurial experimentation (C4) or municipal level public procurement leading to market formation (C2). The primary focus on niche creation and the innovation system lacks a focus on circular economy aspects such as reuse, recycling and modularity; reflecting the push to develop a new market for forestry products.

In Finland, knowledge development and diffusion (C1) suffer because projects have been scattered both geographically and in terms of actors. In Sweden, municipalities cannot introduce requirements exceeding the building code, partly to facilitate standardization and industrialization, which has a negative effect on market formation (C2).

5.7.2 Regime destabilising policies

Changes to building structural fire safety codes to permit wooden framed buildings to exceeding two storeys was a significant change in regime rules (D2) in both countries. This has had the effect of removing the monopoly that concrete and steel frame construction had held in the multi-storey market, and thus opening the market to wooden framed buildings.

In Finland, the fire-safety provisions of the National Building Code of Finland were changed in September 1997 to allow the use of wooden building frames and wood in façades for buildings of up to four storeys. The provisions were changed again in April 2011 to allow these uses of wood in residential and office buildings of 5–8 storeys. Wood buildings of more than two storeys must be equipped with automatic fire-extinguishing systems. In Sweden, the use of wooden building frames for more than two floors was allowed in 1994, with the introduction of a functionality-based building code (BBR94). Requirements to resist fire to a minimum duration are set for all building irrespective of material. There is no restriction on height, expect that building with normal frames (as opposed to fire-retardant treated wood) require the installation of a sprinkler system. Changes related building code fire previsions that influence wooden construction are ongoing in both countries.

5.7.3 Policy challenges and options

- In Sweden, the systematic work to promote wood construction appears to become increasingly effective in reaching stated objectives, whereas Finland still needs broader (coherence across sectors) and deeper (involvement of all levels of administration) policy engagement to progress.
- Markets for wooden buildings can be supported more actively by using public procurement for niche creation.
- The growing international wooden construction market is likely to demand structural components and prefabricated modular solutions that can be supported by developing standardization and quality criteria.
- R&D support for developing exportable products of pre-manufactured buildings requires specific attention to local traditions, preferences, and logistics.
- R&D in industrial production of wooden multi-storey buildings and on-site assembly in order to meet the increased domestic market demand and enable export.

- Ensure a level playing field for materials in the construction sector.
- Visualise and communicate the environmental arguments of wood buildings over their life cycle.

Table 16. Policy landscape around the multi-storey wood construction innovation system in Finland and Sweden based on the TIS functions (C=creative, niche support functions; D=Destruction, regime destabilisation functions).

Finland	Sweden
Knowledge creation, development and diffusion (C1)	
EU R&D for wood based construction: ERA-NET WoodWisdom-Net (2004-2008), FP7 WoodWisdom-Net2 (2009-2012), ERA-NET Plus WoodWisdom-Net+ (2013-2017) University Programmes: Wood Programme in Architecture and Design (Aalto University); AA qualification in wooden structures (Aalto Pro and Puuinfo Oy)	EU R&D for wood based construction: ERA-NET WoodWisdom-Net (2004-2008), FP7 WoodWisdom-Net2 (2009-2012), ERA-NET Plus WoodWisdom-Net+ (2013-2017) Limited national R&D funding for wood based construction. Knowledge centres at some universities typically in collaboration with industry and regional authorities as triple helix arrangements. Some R&D on component reuse in construction.
Establishing market niches/market formation (C2)	
Emerging changes in public procurement (HE 108/2016 vp); active support (PTT Working Papers 171, 2015)	Municipal wood building strategies adopted; Växjö predominant example with several wood houses. Wood constructions supported through procurement and district planning. Real estate companies push for industrialised produced buildings due to expected lower costs and faster production. LEED v 4.0 (or any other building certification schemes) does not provide enough points for materials yet to provide strong incentives for market creation.
Price-performance improvements (C3)	
Early signs of price-performance improvements	Early signs of price-performance improvements, in particular from industrialised production of buildings.
Entrepreneurial experimentation (C4)	
Public showcase buildings (e.g., Finnish Nature Centre Haltia; Sibelius Hall, Lahti; Metla House), Wood industry showcase buildings (e.g., MetsäWood, Tapiola) New wooden building areas (e.g., Wood City Jätkäsaari)	Largely beyond experimentation. Some actors are actively supporting industrial practices through e.g. demonstration houses. Multi-actor involvement in LCA evaluations for common interpretation.
Resource mobilisation (C5)	
Wood Innovation Network (WIN) (2015-2017) European Regional Development Fund National programmes promoting the use of wood. Sectoral initiatives: Puuinfo Oy (Finnish Timber Council)	Sector initiatives such as the Swedish wood building council, the Swedish Federation of Wood and Furniture Industry, and Swedish wood. Public funding for R&D. Wood Innovation Network (WIN) (2015-2017) European Regional Development Fund
Support from powerful groups/legitimation (C6)	
Governmental Support through strategic programmes	Some municipalities are pushing for wood based constructions. Network of actors promoting wood building. Some support from the Government office, but no specific policies adopted at national level. More research showing that risk for fire and noise levels acceptable in wood constructions. However, insurance issues still connected to uncertainties. More LCA studies conducted; provides better platform for knowledge. LEED v 4.0 provides some impetus for bio based materials.
Influence on the direction of search (C7)	
Funding of national programmes promoting the use of wood: Wood Construction 2000; Wood in Construction	Governmental funding of project Trästad 2012 to promote wooden buildings, knowledge diffusion, and busi-

Technology Programme 1995–1998; Year of Wood 1996; Time of Wood 1997–2000 Campaign; Wood Europe Wood Finland 1998–2005; Programme for Promotion of Wood Construction 2004–2010 Strategic Programme for the Forest Sector target: 10% market share for wooden multi-storey buildings and the exports of processed wood products increase by EUR 0.5 billion a year. Articulation of demand from leading customers low	ness models. Currently changed to “Trästad Sverige” coordinated by County administrative board of Västerbotten.
Control policies (D1)	
None	None
Significant changes in regime rules (D2)	
Changes to the National Building Code of Finland: wood buildings up to 4 storeys from 1997, wood buildings up to 8 storeys from 2011	Changes to Building code, standards: wood buildings exceeding 2 storeys from 1995. Some municipal initiatives in building for own use. Wood constructions supported through district planning in some municipalities; other buildings not allowed.
Reduced support for dominant regime technologies (D3)	
None	See above.
Changes in social networks, replacement of key actors (D4)	
None	The Swedish Association of Public Housing Companies, together with other actors want to promote industrialised and standardised building and view building in wood as an opportunity.

5.8 Concluding remarks

Multi-storey wood construction has been a fairly stable market with a small market share, despite of its advantages compared to other construction materials when it comes to industrialised production, rural job creation and reduced environmental impact. Concrete is still clearly the dominating paradigm in the segment of multi-storey construction. In this respect, no major difference between Sweden and Finland exists (Table 17). However, the market share of wood for flats in new multi-storey buildings has been around 10% in Sweden over the last decade. In Finland, the tiny market share of around one percent has only started to grow in the middle of 2010s, despite of the rather similar industrial heritage and structure in these countries, and despite of the national support programs in Finland. Lack of wood building strategies at municipal level in Finland may partly explain the slower growth. There are clear signs of increased volumes and expectations of further growth in the market for the coming years, with new production capacity on its way. Even if this follows the general increase in construction, there are also expectations of higher market shares for multi-storey wood buildings.

Raw material

The environmental argument in favour of wood has become stronger over time. Due to more energy efficient designs and less carbon-intensive energy supplies, the climate impact for new buildings is no longer dominated by the use phase. Hence, the contribution from raw materials and the construction phase has become more significant. The environmental dimension also involves issues such as efficiency in the use of raw materials, transport in connection to construction sites and waste generation – factors that are positively influenced by an increased industrialisation of the design and construction process. It should though be noted that multi-storey wood buildings often have important components made of concrete. It is thus a matter of finding suitable combinations of the materials.

Raw material is not a limiting factor for multi-storey wood construction either in Finland or in Sweden. As this segment currently uses less than one percent of the sawn timber produced, there is room for even a radical increase in wood multi-storey construction projects in both countries. The growth in other fields of bioeconomy in Finland and Sweden is unlikely to endanger the availability of raw material, due to the traditionally different raw material base of timber and other wood fibre products.

Products, processes and innovation

Product innovation has led to an improved basis for design. Essential quality parameters include acoustics, fire safety, modularity, aesthetics, add-on to existing buildings, etc. These not only improve efficiency but they are also likely to make the multi-storey wood buildings more appealing to the users.

Advanced industrialisation of the design and construction process is expected to result in cost reductions.

Other benefits from the industrialisation of the construction process include shorter lead times, improved logistics and increased raw material efficiency. Wood is well suited for an industrialised process and increased pressure for productivity will favour wood as basis for construction.

Actors and capacity building

The market for multi-storey wood construction is not dominated by the traditional big construction companies. Instead, it has become a niche where a handful of SMEs, often with an origin in the forestry sector, represent both the current volumes and the growth in the market. Along with the growth potential of the multi-storey wood construction market, also incumbents in the construction sector show more interest in the ongoing and planned wood construction projects. However, neither the overall construction market nor the market for large wood buildings can be considered very competitive. BoKlok founded by IKEA and Skanska is a significant actor in the segment not originated in the forestry sector, and is present on markets beyond Sweden and Finland.

The experimental nature of planned and finalized building projects underlines the need for more systematic knowhow and experience development. Low number of references from complete projects among design and construction actors slows down learning, as well as skills and technology development. Limited number of remarkable showcases easily result in lower credibility. Consequently, multi-storey wood construction needs institutionalisation and additional capacity building, among e.g. planners, architects, construction companies, fire safety specialists, etc., in order to compete on the same grounds as the established materials, especially concrete. Wood construction is more efficient when a project is planned for wood modules or elements from the very beginning of the process.

Circularity in wood construction

Circularity is overall not very well developed in the case of large wood buildings, nor in the construction sector in general. The concept is known among the actors, but it would need clear and shared definition to improve common understanding. The buildings are built to last and the issues of renovation, upgrading or decommissioning are not really addressed in the design process. The underlying argument is that wood is a bio-based material that can be incinerated and hence there should be no real problem.

Traditional wood preservatives cause problems in reuse, recycling and incineration. Innovations in wood preservation reduce needs for separation and special treatment in waste streams, thus increasing opportunities for circularity.

With regards to modularity, two interesting developments were identified: use of modules stacked up to four layers for temporary housing, and the role of modules in renovations and add-on to existing buildings. Both of these solutions represent innovations in the multi-storey construction segment.

In terms of circularity, construction business focuses on building projects (short term), whereas real estate business puts more emphasis on life-cycle (long term) costing. In order to increase circularity in wood construction, we need more effort to improve collaboration, dialogue, planning and ecosystem development.

Future visions for circular bioeconomy

Multi-storey construction market has a significant potential for circular bioeconomy, emphasizing efficient solutions for the user and efficient production methods. Even if public procurement is important as an initial action, the sustained growth of the segment hinges on a wider market penetration including demand from private sector. The first references from local customers are vital for success in terms of exports and potential further internationalisation of wood building businesses.

Finnish and Swedish actors have, at least from a supply perspective, a good starting point, to aim for a significant global position in multi-storey wood buildings. However, this aim involves further development among Nordic material suppliers, designers, logistics and construction companies. Highly industrialised production of wood buildings is developing. Successful market penetration entails understanding of users, which leads to customized production and specific designs for selected export markets.

New wood materials (nanocellulose, non-toxic preservatives, etc.) and service concepts are significant for the multi-storey buildings.

A policy reform to make renovation more favourable than demolishing old and rebuilding, as well as RDI funding to the field of wood reuse could support the circular ecosystem development.

Challenges still remain. First, the mind-set of conventional construction sector should change towards accepting wood materials, and the preferences in the market should change in favour of recycled construction materials. The creation of demand for modular wood construction from public and private sector might also be challenging. The possibilities of wood recycling are also limited, as the reuse and recycling infrastructure has been virtually non-existent.

Table 17. Comparison of the multi-storey wood construction sectors of Finland and Sweden.

	Finland	**Sweden**
Actors	Domestic production and design of wood buildings focused on small size one family solutions. Innovations in materials leading to advances in industrialisation of construction processes. A few SMEs dominate the present volumes both in advanced materials and in wood frame construction. Incumbent construction companies starting to show more interest.	The target segment goes beyond single family houses and caters for environmentally conscious construction in general. Municipalities and real estate companies interested in innovation and industrialisation in order to produce affordable and quick-deployed housing. A number of SMEs originating in the forest industry supply the market. To a large extent self-learned. Production capacity is increasing. Select municipalities drive the use of wood, as do select real estate companies.
Processes of commercial scale operations	Breakthroughs in materials and prefabricated elements, and modular systems for multi-storey construction. Circularity poorly developed.	The growing market is creating favourable conditions for modules and elements from wood. Temporary modules fit circularity, else limited reuse/recycling. Technical innovation allows multi-storey wood construction to cater for both cost conscious segments and more individual designs.

Products	Mainstream from domestic raw material sources. Product lifetime long. Potential in modular building systems, but their domestic production underdeveloped.	Some examples of temporary buildings for lease/rent. Some examples of add-on/expansion of existing buildings. Industrialised and standardised products lead on to shorter construction time.
Market formation	Public and industry show case buildings available. Stora Enso is the only significant global actor that could push the markets towards circular bioeconomy in wood construction.	Some municipalities and real estate companies drive wood construction. The growing volumes create bottlenecks making incumbents seek alternatives such as wood frames, and drive business in general for the wood construction industry.
Research and development	R&D programmes and university programmes available for wood structures.	Technical development, environmental assessment and industrialisation are among the key research areas. Regional triple helix collaboration in select forest areas.
R&D funding	EU and ministries.	Dominated by domestic sources, including Vinnova and company funds.
Policy	Government support to wood construction through strategic programmes with target levels for the market share of multi-storey wood buildings. Changes in public procurement may promote circular economy.	Focus area for national government but no explicit incentive programmes. No support for circularity. Some regional bodies promote wood construction through planning processes. Municipalities procure wood buildings, typically for their own use.

Photo: Image bank of the Environmental Administration/ Riku Lumiaro

6 Biorefinery case

Biorefineries are viewed as factories and as broader systems of processes that convert biomass into a spectrum of marketable products and energy. It is desired that this is achieved in a sustainable fashion, an aim that requires that society significantly improves utilisation of biomass raw material in conversion to products. While wood is just one potential feedstock input, this analysis focuses on 'wood biorefineries' in Finland and Sweden. To date these that have mainly been developed as "extended pulp mills" or biofuel plants. Biorefineries have the potential to produce multiple outputs that will primarily be directed to industrial customers.

6.1 Aim and methods

A case addressing biorefineries was selected, as we perceive these technological endeavours to represent the emerging bioeconomy, and the renewal of manufacturing towards renewable feedstocks, in an almost iconic form. However, this work also departs with the view that biorefineries currently present themselves within only a portion of the 'circular economy', and thus only encompass only a subset of circular economy aspects. This report is primarily focused on wood-based biorefineries, the current pillar of Nordic bioeconomy efforts. The status of Finnish and Swedish forestry companies, as world leaders in forest sector technology development, also underlines the importance of biorefining innovation as an important future market for Nordic technology innovators and knowledge providers.

Another issue to be addressed within this discussion is the important contribution of existing forestry sector activities and forest by-products to the national (renewable) energy balances of both Finland and Sweden. Biomass for bioenergy is a vital component for achievement of climate goals, however, competition between markets for biomass as 'an energy carrier' and markets for feedstocks to biorefineries must be seen as a challenge to be avoided or overcome.

Another factor stimulating interest in forest sector biorefining is the emerging stagnation of the pulp and paper sectors in the Nordic countries and North America (Näyhä & Pesonen 2012). Related to such developments, many hold that sectoral diversification into a richer portfolio of businesses and value chains offered by biorefineries makes sound economic sense.

This case has been produced as a desktop study supported by interviews with forest-sector firms and authorities experienced in biorefineries, biochemicals, advanced biofuels, and biomaterials (Table 18). In addition two stakeholder discussions were organized and the presented ideas are included in the report.

Table 18: Data sources for the biorefinery case.

Finland	Sweden
Forest companies 4 interviews (MetsäFibre, Paptic, StoraEnso, Repolar) Universities 3 interviews (Aalto, VTT, Åbo Akademi) In addition to the interviews and desktop studies the data collection included conference observation, participation in steering group work of a research project.	Forest companies: 3 interviews (Domsjö, Södra) Research institutes: 2 interviews (SP, LTH) Industry organisation: 1

	Supporting Swedish projects
	IIIEE *f3* study (Swedish Energy Agency, Swedish research partners, and Vinnova): *Systemic constraints and drivers for production of forest-derived transport biofuels in Sweden* 10 project case studies of large-scale advanced biofuel projects (fuel biorefineries). Data collection via interviews (>20 expert interviews) and desktop study (literature review, web based surveys). Work supported by a project webinar, supplementary interviews and material from project proponents. Documented in (Peck et al. 2016)
	IIIEE *f3* study (Swedish Energy Agency, Swedish research partners, and Vinnova): *Enabling the transition to a bio-economy: innovation system dynamics and policy* Data collection: 10 semi-structured in-depth expert interviews. Informant organisations included the AEBIOM, SVEBIO, the European Biofuel Technology Platform, the Swedish Energy Agency, utility E.ON Sweden, SEKAB (ethanol), and SAKAB (waste management) supported by review of academic, industry, NGO and policy documents. Documented in (Palgan & Mckormick 2016)

6.2 General characteristics of biorefineries

The concept of 'biorefining' is broad and numerous different facilities are termed 'biorefineries' According to both the literature, and informants to this study, the term biorefinery reflects an analogy with oil refineries where the crude oil raw material is efficiently processed to a number of products in a way that minimizes the low-value fractions of crude oil. Moreover, there is a general agreement that the biorefining concept encompasses several biomass feedstocks and conversion processes to yield both intermediate and final products (Novotny et al. 2014). As there have been many definitions since an early biorefining model was proposed by Levy et al. (1981) a widely accepted definition put forward by IEA Bioenergy Task 42 (IEA, 2009) is used to set the scene for this text: *"Biorefining is the sustainable processing of biomass into a spectrum of marketable products and energy"*. It should be noted, however, that the sustainability aspects of biorefineries are not well defined and therefore there is a risk that sustainability is too readily assumed in connection to biorefineries. Key aspects in this regard that are referred to in the Finnish and Swedish bioeconomy strategies include climate change mitigation, nutrient recycling, clean technologies and efficient recycling of materials. This case also seeks to highlight the links between the bioeconomy and the circular economy.

Biorefineries are viewed both as factories and as broader systems or sets of processes. However, the products of biorefineries rarely serve a single or well defined societal function such as mobility or energy. Therefore, the analytical framework of societal transitions used in the other cases of this study does not lend itself very well to biorefineries and is used only to a limited extent.

6.3 Wood-based biorefineries in Finland and Sweden

While biorefineries will include many different biomasses as raw materials, the focus of this case is predominantly upon wood-based biomass. Industrial renewal of this sector towards 'biorefining' has been high on policy agendas in recent years (Näyhä & Pesonen 2010, Teräs 2015). This is particularly so in the countries of the Northern hemisphere that are rich in forest biomass resources and have well developed pulp and paper industries. The forest sector in particular has the opportunity to build upon existing knowledge, networks, technologies, and the existing socio-technical regime for biorefining process development (Peck et al. 2016). Sweden and Finland are key countries in this regard and the potential for positive economic impacts may be substantial.

The fact that pulp production facilities already "*produce a variety of bioproducts like fuels, fibres, and chemicals from wood-based biomass" (Näyhä & Pesonen 2012)* leads to a situation where a number of experts already consider a modern kraft pulp mill to be a biorefinery; albeit, a rather simple one that produces fibres, energy and some chemicals (Figure 10). However, significant development is required to move beyond this status and broaden the spectrum of products and improve the utilization of all wood components. At present, the facilities that can be classified as wood biorefineries in Finland and Sweden are generally parts of existing forest industry value chains. However, fuel production initiatives—that have also been perceived as biorefinery efforts—have also developed separately from the existing forest industry.

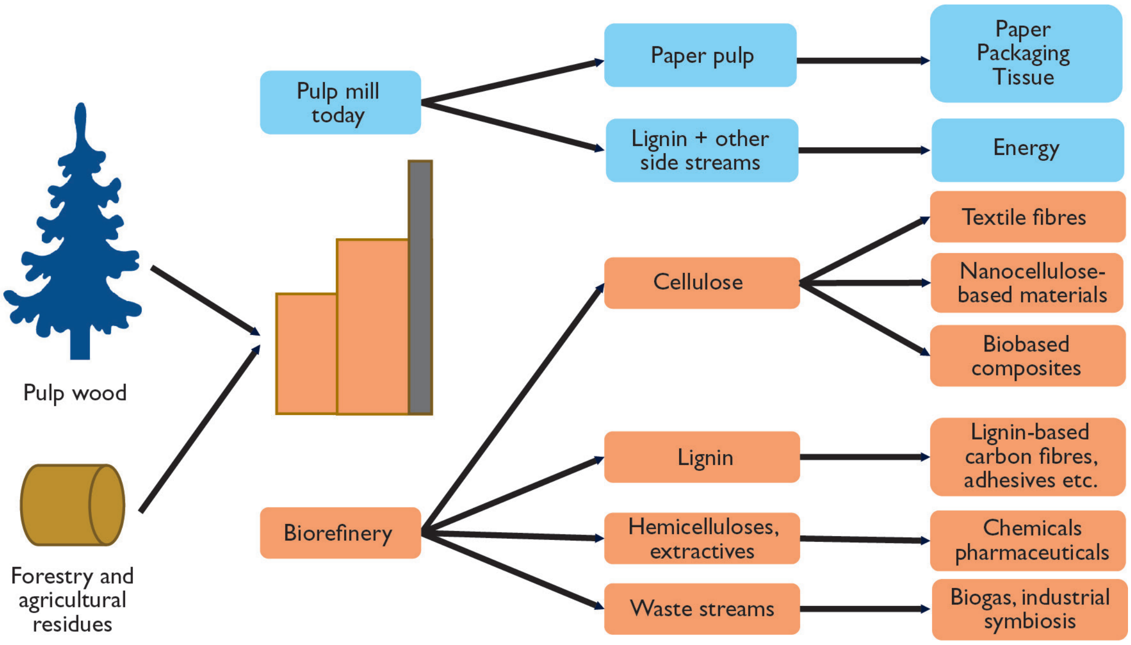

Figure 10. Development of a kraft pulp mill towards a biorefinery. Modified based on RISE (2015)

6.3.1 Products and directions for Nordic biorefining

Two primary objectives characterize the approaches within Nordic biorefining. Firstly, they aim to address bioeconomy objectives by replacing fossil raw materials with biomass. Secondly they have the goal to achieve the biorefining ideal of full utilization of biomass to create marketable products. Some of the niche innovations observed within such categories may have the potential to start transitions in their own value chains.

Aiming at replacing fossil raw materials

In addition to the creation of biomass-based fuels mentioned in the opening of this case, R&D efforts have found applications for various fractions of lignocellulosic materials (see also Table 19). These offer replacements for fossil derived materials. Examples of products and end uses include: lignin-based binders, adhesives and rheology-control chemicals; base chemicals for polymers (e.g. butanediols) that are derived from substances such as hemicellulose-based furfural chemicals; and talloil–based chemicals.

Informants to this study also relate that there are interesting developments in the area of renewable barrier materials. These offer replacements for the technically vital plastic barrier (e.g. in paper-based containers for perishable goods). Further, new products providing replacement of plastic bags with fibre-based bags by Paptic Oy serve this aim.

In many cases where replacements for incumbent fossil derived materials are seen as feasible, the progress towards such replacement remains largely theoretical. While there seems to be new potential in creating new markets for composites based on reinforcement by biomass fibres (e.g. for replacement of glass fibres), thus far the development of renewable resin components for composites is not well advanced. As described in section 6.5 there are now research initiatives that aim to develop fully renewable composites.

Seeking efficient utilization of all wood components

When focusing upon a lignocellulosic biomass such as wood, the main components of interest for production include: 1) cellulosic fibres, 2) lignin, 3) hemicelluloses and 4) extractives. These items are already utilized to varying extents in today's pulping processes (Table 19). Moreover, pulping processes are often run using heat and power generated with biofuels derived either directly from wood feedstocks, or from woody biomass process byproduct streams.

Table 19. Existing and novel products of biorefineries based on the two main chemical pulping processes kraft and sulphite pulping (wood composition data from Alén (2000)).

Component	Kraft	Sulphite
Cellulose fibres (cellulose 40 % of wood biomass)	Paper grade, increasingly also dissolving pulp for e.g. textile fibres	Often dissolving pulp for e.g. textiles and production of cellulose derivatives such as cellulose acetate.
Lignin (20-30 % of wood biomass)	Incinerated in the recovery boiler for heat and electricity; main aim to increase electricity production, increasingly also separated for various lignin products such as adhesives, carbon fibres etc.	Lignin products are used for e.g. binding purposes and rheology control, e.g. in concrete (less cement needed).
Hemicelluloses (25-35 % of wood biomass)	Mostly not used; either precipitated on fibres or released with effluent; an exception being xylitol (for which there are also other sources)	Base chemicals (for e.g. polymers) such as furfural produced e.g. by Lenzing, Austria, or propanediols by Borregaard, Norway.
Extractives (less than 5 % of wood biomass)	Tall oil fatty acids used for various chemicals (e.g. alkyd resins, dimer acids, surfactants, cleaners, oil field chemicals, lubricant esters and other chemical derivatives) or biofuels (e.g. HVO); sitosterol used as a food additive.	Depending on process, special chemicals may be easily recoverable, e.g. cymin for fragrances.

Examination of the table above demonstrates that today's sulphite pulp mills have developed the "multi-product" biorefinery concept somewhat further than the present status of kraft mills. Historically this has predominantly been in order to compensate for less efficient energy recovery and inferior fibre quality of sulphite mills. With the growing interest in biorefineries this has turned into a form of advantage. As a leading example, the Norwegian company Borregaard now lists lignin derivatives rather that the cellulose fibres in first place within their sulphite pulping process-based business area portfolio (Borregaard 2017).

6.3.2 Progress thus far

Table 20. provides details of a number of existing, planned, or proposed biorefinery activities across Finland and in Sweden. This selection focuses on those aiming for commercial scale, or relevant to commercial scale operations (e.g. scale demonstrations). While this tabulation covers many of the Finnish and Swedish initiatives, the status of initiatives change regularly and new initiatives appear. This should thus be seen as an indicative overview of the majority of ongoing initiatives relevant to this case; not a definitive listing.

An aspect of biorefining practice that is important to recognise when seeking to understand progress is the strong emphasis on bioenergy and biofuels production in much of the current discourse addressing biorefineries (e.g. WEC 2010; Star-COLIBRI 2011). Indeed, we observe that numerous scientific discussions and analyses (including several cited elsewhere in this discussion) clearly introduce the 'multi-product portfolio and value-adding' aspects of biorefining but then proceed with discussion of a production facility designed to only deliver biofuels and/or bioenergy. Informants to this study perceive this situation to be misleading and even problematical. Such concerns centre upon two key areas: first that feedstock supplies are constrained but the amounts of energy traded on markets are immense. Thus, biomass can deliver at best a partial solution for societal fuel and energy needs. Second the value-added in biomass-fuel production chains is considered to be quite low.

Table 20. Examples of biorefinery activities in Finland and in Sweden.

Activity	Owner	Products	Stage	Comments
		Finland		
Äänekoski bioproduct mill	Metsä Fibre/ Metsä Group	Softwood and hardwood pulp, energy (kraft)	Commercial, under construction	Welcome other operators to broaden the product range, but do not intend to produce them themselves
Sunila pulp mill LignoBoost	StoraEnso	Lignin in dried form (in addition to the earlier products kraft pulp and energy)	Commercial, on stream	Part of lignin replaces fossil fuels in the lime kiln, part is sold.
Enocell, dissolving pulp	StoraEnso	Dissolving pulp on one of the two kraft pulp lines	Commercial, on stream	Reconfiguration because of reduced demand of paper pulp and good demand of textile fibre raw material.
Kemijärvi pulp	Consortium, public actors	Dissolving kraft pulp	Early planning stage	Reuse of old pulp mill
Kuopio pulp	Consortium of investors	Kraft pulp	Early planning stage	Greenfield mill on existing industrial area.
Lappeenranta biodiesel plant	UPM	HVO biodiesel for transport use	Commercial on stream	Raw material tall oil debated, because availability limited, estimated production in Finland is in the range of 300000 t/a.
Kajaani Cellunolix	St1	Ethanol from sawdust for transport fuel	Planning stage	Planned capacity 10 000 t/a. By-product lignin for energy production[18]
Fortum Otso, Joensuu	Fortum (UPM)	Pyrolysis oil from wood chips	Commercial, on stream	50000 t/a, used on Fortum power plant, or sold to district heating plant
Kaidi biofuel Kemi	Kaidi (China)	biodiesel from wood	Planning stage	
Scandinavian Biopower Ristiina	Momentum Capital (NL)	Biocoal pellets	Construction stage	Planned capacity 200000 t/a.
Green Fuel Nordic Iisalmi ja Lieksa	Green Fuel Nordic Oy	Pyrolysis oil from wood	Planning/ construction stage	Lieksa capacity 24000 t/a oil.

[18] See: http://www.st1.fi/puhtaampaa-siksi-halvempaa

Activity	Owner	Products	Stage	Comments
		Sweden		
Domsjö Fabriker, Örnsköldsvik	Aditya Birla Group	Dissolving pulp (sulphite), lignin, ethanol	Commercial on stream	230Ktpa cellulose Lignin 12Ktpa Bioethanol 17ktpa.
Södra, Mörrum	Södra Skogsägarna	Dissolving pulp (kraft), heat and power. Total plant capacity circa 0.5Mtpa.	Commercial, on stream	Dual lines producing dissolving pulp from hardwood/softwood. 2016 onward increase capacity by 90Ktpa to (40Ktpa dissolving pulp).
StoraEnso Innovation Centre for Biomaterials	StoraEnso	Research centre, identification of business opportunities	R&D, pilot plant planned in Louisiana, US.	Objective to expand into broader biomaterials business (with platform chemicals).[19] US pilot: bagasse and other production waste.
Chemrec (and Domsjö Fabriker), Örnsköldsvik	Chemrec	Output: DME or methanol	Advanced planning stage achieved.	Entrained flow biomass gasification, black liquor, 100 MW≈ 1000 GWh/yr. Taken to commercialisation stage. Now indefinitely postponed.
Bioraff (biorefinery) Norrtorp	SAKAB et al., Kumla	Methanol and/or methane, heat	Advanced planning stage achieved.	Gasification, forest residues & waste. Taken to commercialisation stage but on hold. 250MW ≈ 1800 GWh/yr
GoBiGas, Göteborg	Göteborg Energi	Methane, heat	Stage I ongoing commissioning. Phase II on-hold.	Indirect gasification, solid biomass (wood pellets 2015, 2016 forest chips). 20MW (≈100 GWh/yr) – phase I. 100MW (≈800-1000 GWh/yr) – phase II.
Värmlands Methanol	Hagfors Värmlandsmetanol AB,	Methanol, 10 GWhpa surplus heat in district heating	Planning stage. Project on hold.	CFB gasifier, wood chips, 110MW ≈ 600 GWh/yr Technology: ThyssenKrupp industrial solutions (TKIS)
Bio2G E.ON Sverige AB	E.ON Sweden	Methane, heat 10MW internal power potential for $N_{2liquid}$ and for biorefinery setup for CO & H_2	Advanced planning stage achieved.	Project on indefinite hold. Gasification, wood chips, forest residues. 325MW_{th} feedstock 200MW biogas ≈ 1600 GWh/yr
Renfuel	Renfuel AB	Lignin oil for fuel and chemical synthesis	Industrial scale under construction	Catalytic conversion of lignin into lignin oil. >3000tonnes/yr >20 GWh/yr Co-located with the Nordic Papers pulp mill in Bäckhammar, Värmland.
Preem - Gothenburg	Preem	Diverse: HVO from bio-diesel, Biooils to diesel Solid biomass to diesel (in planning)	Commercial: on stream	160 000 m^3/year ≈ 1600 GWh/yr Largely Neste technology system but co-processing strategy in refinery significantly alters capital plant investment requirements.
SunPine, Piteå	Södra, Preem, Sveaskog, Kiram and Lawter	Raw tall diesel separated from raw tall oil	Commercial: on stream	100 000 m^3/year ≈1000 GWh/yr

[19] See: http://biomaterials.storaenso.com/AboutUs-Site/Pages/The-Stora-Enso-biorefinery-concept.aspx

The projects presented in Table 20 are in general, large and capital intensive. Further, the majority are developed by established industrial actors of large scale in the forest and energy sectors. This is interpreted here as being evidence of a growing interest by incumbent organizations. However, most of them can be described as amendments to modern but traditional pulp mills, or initiatives focused on the production of biofuels. The projects display markedly varying levels of potential disruption to the socio-technical regime (generally pulp and paper and/or transportation fuel regimes). The deployment of "more ambitious" biorefineries both in the EU and in Sweden and Finland has been relatively slow, and it has not truly reached the industrial mainstream. The term "more ambitious" used here refers here to biorefineries that follow the definitions calling for a significantly broadened product spectrum, a suite of value added products, and efficient use of biomass in the path to marketable products. Across Europe, most of such facilities are at best demonstration or semi-commercial plants (Bacovsky 2014). While Sweden and Finland are clearly frontrunners in the area with several large demonstration and pilot plants (Peck et al. 2016), the fact remains that a number of the high-profile projects have predominantly pursued biofuel production platforms. Prominent examples in Sweden include a large-scale demonstration plant for solid biomass gasification GoBigas I by Göteborg Energi, pilot plants for entrained flow gasification of black liquor by Chemrec, and a pilot plant for lignocellulosic ethanol in Örnsköldsvik by SEKAB and university partners (Hellsmark et al. 2016). In Finland, wood gasification for biofuel production was piloted by UPM and StoraEnso, but the pilots have not led to commercial production. A similar process is planned by Kaidi, but final decisions have not been taken. Further, the broadness of the product spectrum of the Metsä Fibre Äänekoski mill remains to be seen.

6.3.3 Important considerations for upscaling

It is observed that at this point in their development forest industry bioeconomy efforts find themselves in a phase of 'competition and selection' – both in terms of competing for feedstocks that are subject to varying availability constraints, and in terms of support for research and development

Raw material constraints

A major challenge for the scale-up of biorefineries, especially for those including large-volume low-value products in their product portfolio, is the sufficiency of raw materials and the land required for their production (WEC 2010, Star-COLIBRI 2011). Even where large quantities of biomass may be theoretically available for collection in a certain region, economic and logistic constraints limit the size of a facility.

Further, and as stated in Section 2.4., while economies based on forest-based bioproducts are considered to offer new business opportunities, there is growing recognition that bioeconomy is not always synonymous with a sustainable economy, and that a biorefinery does not automatically qualify as a sustainable production unit. Many major parts of today's bioeconomy are neither resource efficient nor entirely renewable. If there are side-effects such as resource conflicts, reduced food security, biodiversity loss, or increased greenhouse gas emissions caused by land use change—such as observed within the production systems for today's first generation biofuel projects—then a biorefinery project has the potential to be unsustainable.

In Finland, there is an ongoing debate on the sufficiency of wood raw material, with key focus on competition between the actors harvesting energy wood for power plants and wood fibre producers. The current levels of support for renewable energy complicates the market, and the various biorefineries in the planning stage increases the nervousness of incumbent market actors. Major concerns for incumbents are the potential for effects on the availability and price of the raw materials, and disruptions to their supply side logistics chains.

Importantly, there is already tangible competition for some processed biomass fractions. Tall oil is currently subject to competition, and also an example of how a market situation can be skewed by policy intervention. In recent years, competition for (supply volume limited) tall oil has increased between fuel producers and chemicals producers. Further, the ability for the energy market to compete with the chemicals market has been exacerbated by policy support for energy use (e.g. fiscal support for utilization of tall oil in transportation biofuels). Both representatives of the chemicals sector and informants to this study from other branches hold that this disadvantages the manufacturers of tall-oil-based chemicals.

Lignin is also gradually becoming an example where feedstocks for the bioeconomy can be constrained. At present a number of producers themselves are actively assessing whether using lignin as an energy source in their own facilities is more valuable to them than investing resources in the separation of lignin for sale to a burgeoning bio-based chemicals industry. In Finland, informants representing modern and energy-efficient pulp mills with excess energy to sell, indicated that there is a need to develop more value-added products from lignin than energy. On the other hand, energy production from black liquor is an important component of the renewable energy strategy for Finland, and an important component of the overall energy mix in Sweden.

Constraints for research, development and commercialization

In the previous (Table 20) a considerable number of biorefinery projects were presented. A significant number of these reached advanced planning stage but have not entered the commercial phase. Deeper examination of individual cases (e.g. see for instance 10 detail cases documented in (Peck et al. 2016) reveals a range of economic, technological and policy-related issues that constrain both the bioeconomy in general, and biorefineries in particular. Importantly, many such projects have failed to secure funding for technology upscaling and others have been halted by (chiefly) financing issues, and have not been built at commercial scale. This indicates that along with the promises that biorefineries offer there also exist significant factors hindering their diffusion.

Demand for biomass-based products is also clearly affected by the price of fossil oil; the principal competing feedstock for biomass. Oil prices were generally high during the period 2006 to 2014, which opened a window of opportunity where many of the biorefinery projects listed in this discussion were planned and developed. Prices for petroleum feedstocks are now very much lower; and current low(er) oil prices present an environment that is not nearly as attractive for investments to produce alternative fuels, chemicals or products as it was at that time. In Finland, the distribution mandate and related tax exemptions of transport biofuels are now perceived to ensure a sufficiently stable market to support investment in biomass-based fuels derived from forest biomass. However, in Sweden informants indicate that both a consistent oil price of greater than circa 60 USD/bbl and medium-to-long-term fiscal measures (>10 years), or significant fuel quota mandates, is required to support investment in most new plants for advanced biofuel production. The current system of 3 year cycles of tax incentives has not provided sufficiently long-term financial security for most projects.

The root cause of barriers that have prevented project execution in these Swedish cases were a general lack of political stability (i.e. short time horizons in the policy support schemes and political goal setting). Industry informants indicate that eroded confidence (i.e. increased risk perception levels) has markedly increased challenges related to securing project financing (Peck et al. 2016), and that these effects that can have longer-term impact, even if stability is improved in the short to medium term. A general lack of security for biorefinery investments has been recognised as a key constraint for biorefinery development both in the literature, and by the interview experts specifically in relation to the Swedish (Peck et al 2016, Palgan & McCormick 2016) and Finnish situations (Teräs 2015). Investment risks are also amplified by the high capital intensity of biorefinery facilities. While large funding schemes for first-mover support (e.g. NER 300)[20] have been offered, or put in place, several expert informants in Sweden still stress the need for more favourable national and EU funding schemes for pilot and demonstration biorefineries to promote their development.

6.4 Biorefineries and circular economy

As has been indicated in Section 2.1, the bioeconomy concept lies on the left half of the circular economy model used to support this discussion. Bioeconomy circularity is most often communicated in terms of the natural processes that ensure degradation (mineralisation) of by-products and the cycling of carbon dioxide into growing biomass. Tied as they are to plant growth rates and life cycles, these processes take time. Moreover, the circularity is not tied to just biomass that enters the bioeconomy as organic material also remains in the soil for long periods of time. It is also important to note that while the circular economy model considers energy recovery from waste as a leakage to be minimised rather than a desirable part of the circular economy, biomass-to-energy systems are an important component of societal efforts to decrease the carbon intensity of energy systems; and a biorefinery is a natural place for by-product energy recovery. Applications can include energy recovery from by-product streams to drive processes, to feed broader societal energy systems (e.g. heat and power), or to create functional transportation fuels. As such, the concept of 'leakage' in the case of biorefineries cannot be applied as a 'one-fits-all' (negative) generalisation but should be assessed on a case-by-case basis.

Indeed, there is a long value chain from a biorefinery to the use phase of the numerous end products, where the possibilities for circular economy are worthy of evaluation. With this in mind, biorefineries could be visualised in the materials production system in the middle of the Figure 1 illustrating circular bioeconomy. They have potential to operate as a renewal hub feeding on virgin biomass, on biomaterials recovered from production processes, or on biomass recovered as post-consumer waste.

6.4.1 Efficient use of the raw material

Biorefinery concepts presently in operation appear to be largely based on pursuit of increased efficiency of biomass use and utilization of the process chemicals used; phenomena where circularity often applies. This is the approach presented by Sitra in their report on the possibilities of the circular economy in Finland (Arponen et al. 2015). Efficient use of natural resources in the manufacturing chain is an essential part of circular economy, but by no means the whole story. Rather, it can be observed as a natural part of incremental innovation in any cost-conscious company in large-scale manufacturing. Efficiency of manufacturing must also include the continuous improvement of process-internal chemical and by-product recycling. An important consequence, with implications for circularity, is that as the processes become increasingly closed (as is already the case e.g. in kraft pulping) it is crucial that the concentration of substances in the process, and their potential impacts, is well understood and managed. This again underlines the need for ongoing fundamental research on wood chemistry and processes as circular and bioeconomy efforts are pursued.

Informants to this study also emphasise that it is vital that biorefineries ensure that the large fractions are efficiently used in various marketable products. As such, the "multi-product" strategies of biorefineries also contribute to raw material efficiency.

[20] For discussion of one key EU support mechanism, the NER300 (New Entrants Reserve) that is intended to help large biorefinery-like initiatives forward, see http://ec.europa.eu/clima/policies/lowcarbon/ner300/index_en.htm

6.4.2 Aiming at increased value added

In the interest of both raw material sufficiency and the economic feasibility of renewed manufacturing, a number of expert informants emphasize the imperative for biorefineries to focus on small volumes of 'high value added' products. One argument brought forward by informants that addresses a fundamental issue within this, is that many chemical components of wood are organically complex and as a result have unique physical and/or chemical properties. Their use for energy largely ignores these potentially valuable properties as they are lost in combustion. As examples, wood extractives contain bioactive components with interesting health impacts and the hemicellulose components of wood offer potential platforms for many useful products of the chemical industry. Our observations of R&D projects show that there is potential in increasing the value added of lignin (as one example) by producing carbon fibres or via pursuit of specialty chemicals. Borregaard of Norway, the world leader in the production of vanillin, effectively conserves some of the chemical structures of lignin in its production processes, an application that exemplifies this.

The bulk of the goods delivered by the forest-based industry are, however, still traditional forest products (sawn timber, pulp and paper, energy). One factor that has driven this historically is that the business logic of the industry is based firmly within a 'large volume' or 'scale efficiency' paradigm. Informants indicate beliefs that a prime reason why raw material procurement strategies to pursue very high value-added products have not succeeded in forest industry companies is because of the huge differences in production scale. Further, market knowledge of new value chains outside their sector is largely absent within such forest industry companies.

6.4.3 Recovery and recycling

Actual recovery and recycling of the end use products based on refineries vary immensely depending on the value chain. Moreover, a number of informants have indicated that 'definitions of waste' and the regulatory constraints applied to different 'waste' (byproduct) streams also vary widely. In some instances, 'waste' definitions constrain both efficiency, or circularity efforts (or both). As a positive example, it is important to recognise that the traditional forest industry products of paper and board are already efficiently recycled. Some 70 % of used paper and board are used again as recycled content in paper and board production, where they serve in their fibre-material role. This is close to the practical maximum when applying the current fibre-focused paradigm for recycling. However, it also indicates that a large proportion of potentially valuable cellulosic material is lost; some 30% in this instance.

It is logical that biorefineries will benefit from increased circularity as developments are made along the whole value chain in cooperation with other actors. Full value-chain thinking will also underpin more systematic design of biorefinery products for recovery and reuse, as new perspectives on a range of design aspects are incorporated. Such include: prevention of toxicity, reduction of multiple materials and components in products, design for dismantling and material recovery, and design for utilization of by-products.

6.5 Development of biorefineries towards a circular bioeconomy

Seeking examples of developments towards a circular bioeconomy, the RECIBI project examined specific activities in: 1) biorefinery products with increased value added; 2) processes pursuing increased efficiency in biomass utilisation; and 3) development of whole value chains as distinct from individual processes (exemplified in the RECIBI by textiles and wood construction). Examples were analysed for niche-internal processes, leading to a number of general observations regarding the nature of niche development and systemic transition (see section 2.6.).

Although the general emphasis has been on products with modest value added, several smaller scale initiatives exist for high end products. A case in point includes products targeting medical and health solutions. Examples include xylitol—the classical synthetic sweetener that has long been in commercial production; betulin from birch bark— which is known to reduce cholesterol; spruce resin, which can heal wounds (Repolar, 2017), nanocellulose as a 3D environment for stem cell culture (Malinen et al., 2014, UPM 2017) and HMR[21] lignan, which is linked to a range of positive health impacts (interview, Bjarne Holmbom). The pursuit of such products is in varying stages of commercialisation. They are scattered examples and represent an early stage of niche development. Expectations are general, networks loose and learning is limited because of the scattered nature of the initiatives. Expectations are general, networks loose and learning is limited because of the scattered nature of the initiatives. They are also not connected to the general biorefinery developments as the raw materials are not currently produced in biorefineries.

Improving the value added of various wood components is studied in several Finnish research programmes such as SmartLi (utilization of lignin for example in plywood resins (Clicinnovation, 2017a, ACel (ClicInnovation, 2017b, DWoC (Cellulosefromfinland, 2017), (utilization of cellulose using novel technologies and design as means of adding value). The large consortia serve as platforms for network development.

In Finland, a significant body of work within the existing business areas of pulp and paper industry (especially packaging) pursuing improved recyclability and resource efficiency continue to receive attention. Even if these pursue incremental improvements in the existing value chains, we perceive them as positive examples of design for circularity called for in our study (Uusi Puu, 2017). We observe however, that most circular economy projects seem to concentrate on non-renewable materials and handling of waste streams rather than combining bio- and circular economies. A prime example is the ARVI-project (ClicInnovation, 2017c). However, exceptions are emerging. The new Tekes programme of Smart and Clean growth and its sub-programme BioNets (Tekes, 2017) aims to combine these areas but the actual outcome of the project portfolio is still open.

In Sweden, a range of targeted R&D efforts support biorefinery initiatives. These include annual investments of EUR 600-650 million in new or upgraded production processes in the pulp and paper industry, dedicated human resources working on biorefineries (e.g. 50 researchers and laboratory engineers at one of the biggest divisions within the national R&D company Innventia),[22] and new patents and collaborations with industries outside the pulp and paper community (e.g. automotive and chemical sectors). Further, growing numbers of conferences on biorefining developments have been observed (Novotny & Laestadius 2014).

In Sweden, there is research aiming at knowledge creation concerning the entire value chain including sustainability issues and market potential (RISE 2015). There are projects on wood-based biorefineries and new products from cellulose, lignin, hemicellulose and waste streams within EU research programs (e.g. EU Horizon 2020/ BBI). A number of Swedish national calls for projects and current ongoing research in this area include BioInnovation, ForTex, Skogskemi, BioBuF, Polynol, Swedish lignin-based carbon fibre, and the Swedish Innventia Research Programme.

While communications of Swedish strategic foci do not communicate aims to achieve efficient recycling of materials as clearly as the Finnish communications, informants indicate that efforts to pursue improved recyclability and resource efficiency continue to receive attention in Sweden in a similar fashion as described for Finland above. Sweden does, however, stress the need to prioritise the “recovery of nutrients and energy” (see Table 1; FORMAS 2012).

A forthcoming analysis of networks involved in a total of 118 biorefinery/biofuels related projects funded in Sweden in the period 2002 to 2015 (Bauer et. al. 2017 in progress) shows that R&D efforts have evolved markedly over the past decade. Firstly the analysis indicates that innovation networks are

[21] HRM = HydroxyMataiResinol

[22] See: http://www.innventia.com/en/About-us/ Innventia is currently undergoing reorganisation and merging with other parts of the Swedish national research base. Bioeconomy is raised as a key focus area. (Accessed 12 Dec. 2016)

growing and broadening; secondly it indicates that universities, forest industry actors, and fuel/energy companies have dominated with biofuels being a central theme; but thirdly it seems to provide supporting evidence to views that research institutes involved in materials and chemicals are now taking a larger role, and that more dominant hubs of activity are forming around chemicals/materials organisations (Novotny & Laestadius 2014).

The examples above indicate that the focus for the future development of biorefineries may already be developing to accommodate the needs of the circular bioeconomy, but that the niches are in an early stage of development and have not evolved into a new dominant design that is able to challenge the standard logic and incumbent regime status of the pulp mills. There is, however, evidence that current biorefinery initiatives increasingly place focus on a broader suite of product platforms rather than fuels (e.g. chemicals, renewable polymers and other materials). In addition to emerging market spaces, motivators for this shift are also given as an inherently lower dependence on government regulations or fiscal support (i.e. reduced exposure to political risk) and higher potential business opportunities to leverage forms of environmental branding (i.e. differentiation potential for products, processes or producers).

In particular, it has been noted that the attention of one of the most influential biorefinery cluster organisation in Sweden—"an organisation that aims to pool resources for technology creation and diffusion" (Novotny & Laestadius 2014) —called Processum, has been observed to shift from second generation biofuel technologies to green chemicals and specialty cellulose (Hansen & Coenen 2013).

6.6 Potential environmental impacts of biorefineries

The transition towards the bioeconomy and biorefining is characterised by pursuit of life time sustainability of production and consumption systems. The relevance of this was highlighted when the increasing use of biofuels in the early 2000s led to vigorous discussions about its sustainability. Consequently, the EU introduced a set of sustainability criteria to help ensure that the use of biofuels (used in transport) and bioliquids (used for electricity and heating) is managed in a way that guarantees real carbon savings and protects biodiversity. Only biofuels and bioliquids that comply with the criteria can receive government support or count towards national renewable energy targets (European Commission 2010). Despite the criteria, several challenges remain in evaluating the sustainability aspects from a life cycle perspective, including aspects such as setting the reference system and system boundaries, allocation procedure and parameter assumptions (Koponen 2016).

It has been argued that a large-scale shift from fossil raw materials to biomass may cause new but significant environmental and social problems. Recent research on, and development of, biomass applications increasingly focuses on raw materials not directly competing with food production, i.e. so called second and third generation feedstocks such as wood, wood waste, non-food crops, waste cooking oil, and forestry residues as well as microalgae (Soimakallio et al. 2009). Using wood-based biomass, Finnish and the Swedish biorefineries have strong potential for sustainable production. In Table 21 we discuss some of the environmental aspects related to biorefineries.

Table 21. Important environmental aspects related to biorefineries.

Climate impacts, energy consumption and atmospheric emissions The use of biomass affects the climate change mitigation in three ways: by carbon substitution, sequestration or conservation.[23] In substitution, biomass is displaces fossil raw-materials. The largest benefits are likely take place when biomass carbon is stored in products; because if processed into biofuels, the biomass carbon is immediately released to the atmosphere during the combustion process. Besides the emissions, it is important to consider carbon stocks and sinks. In sequestration, atmospheric carbon moves into terrestrial ecosystems e.g. by reforestation or increasing soil carbon stock. Significant carbon stocks can also be conserved. Harvesting wood reduces immediately the carbon sink and stock, but growing trees begin to restore the carbon stock. In Finnish and Swedish

[23] Soimakallio et al. 2009.

conditions, it takes decades for a forest stand's carbon sink to accumulate a carbon quantity equivalent to that released through final felling and wood use.[24]

Harvesting, processing and transportation of wood requires energy, currently still produced mainly from fossil fuels. As compared to crude oil, wood originates in scattered sources and transport takes place in smaller units. The energy density of wood is lower than crude oil. Hence, more wood-based raw-material may be needed for the same amount of end-product than crude oil. Additionally, processing biomass in biorefineries may consume significant amounts of energy. To reduce the energy consumption and related atmospheric emissions, as well as to improve the energy balance of the whole life cycle, it is important to develop other renewable energy sources (e.g. solar)[25] and to develop the design of biorefinery processes.[26]

Resource depletion

Replacement of finite non-renewable fossil materials is one of the main aims of using wood-based biomass in biorefineries. However, availability of biomass is not infinite, especially taking into account needs of the growing and more affluent global population; even though currently there is no severe competition on wood-based biomass. Resource efficiency is central to diminish environmental impacts of resource extraction and to ensure equal and affordable access to those resources.[27]

Water use

Boreal forests do not require irrigation. During the refining phase, water use does not represent a major issue in Finland and Sweden as water scarcity is not usually an issue. Moreover, industrial scale waste water management is well developed and controlled.

Hazardous substances

Different substances are used and released in the environment during the life cycles of both wood- and fossil based products. In forestry, relatively small amounts of fertilisers and pesticides are utilised deliberately to improve the harvest, although in Finland the forest fertilisation area has doubled between the years 2000 and 2013.[28] In Sweden, the area fertilised is relatively stable and comparable to Finland, and in general fertilization is modest compared to the peak of the 1970s. In regards to crude oil, significant risks are related potential accidents during the drilling and transport phases. Multiple chemicals with varying properties can be utilised in refining and consumption phases of both value chains, but more detailed discussion is beyond the scope of this report.

Land use and ecosystem services

Production of biomass requires significantly more land than the production of fossil raw-materials. In Finland and Sweden, multiple uses of forests are customary even in commercial forests, and while providing the raw-material for biorefineries, the forests can be used for e.g. recreation, tourism, picking berries and mushrooms foraging and hunting. Provision of many ecosystem services is also maintained. However, the introduction of the significant amount of new biorefineries needed to replace fossil counterparts, would lead to an increase in wood harvesting and intensified forest management that in turn can have harmful impacts on biodiversity (e.g. saprophytic species) and ecosystem services such as water retention.[29] Harvesting increases erosion compared to forests in their natural state. Nutrients are transported away from the forest in the wood material, which may increase fertilisation need.

Waste and recycling

An inherent principle of biorefinery concept is to utilise raw-materials as efficiently as possible, thus minimising the amount of side streams in the production phase. Biorefineries produce multiple intermediate products ending to countless end products. It is important to design those in a way so that they are durable and recyclable or repairable; this preventing the disposal of organic waste to landfills.

6.7. Relevant policies

The policy landscape around the biorefinery innovation system was analysed using an analytical framework based on TIS functions as explained in section 2.6. A summary is presented in Table 22.

24 Hildén et al. 2016a.
25 Lanzafame et al. 2014.
26 Moncada et al. 2017
27 UNEP 2016.
28 Metla 2014
29 Antikainen ym. 2015.

6.7.1 Policies and actions supporting niche creation

Finland and Sweden have a long tradition of funding R&D across the various areas of biomass utilization; this has actively supported *knowledge creation, development and diffusion (C1)*. Most biorefinery niche activities have received public funding. Thus, bioenergy in Finland has received a continuous flow of Tekes funding from the 1980s culminating in the BioRefine-program 2007-2012, the BEST programme 2013-2016 and the founding of VTT Bioruukki in 2015. In Sweden, large amounts of funding have also been distributed via a more varied spectrum of funders including Formas, VINNOVA and the Swedish Energy Agency. The latter has particularly directed substantial funding to support a transition to bioenergy from fossil fuels.

Biofuel development has been boosted by strong policies for *market formation (C2)*; their origins precede the bioeconomy discourse, and were originally introduced to stimulate rural development and increase energy security. The EU distribution mandate has developed markets especially for fuel ethanol and biodiesel in the range of 500 000 tonnes annually (10% of the road traffic consumption in the EU). Domestically, Finland aims for much higher mixtures; 30% in transport and 10% in heating oil by 2030 (Government of Finland 2017). In Sweden, the formal demands for transport are lower (Drivmedelslag 2011:319), but in practice the share of biocomponents had already reached 14.8% by 2015 (Statens energimyndighet 2016). An important challenge for policymakers is to avoid strong policy signals that lead to the use of forest-derived resources as fuels at the expense of potentially more valuable biorefinery products. Ensuring that the impacts of forest based fuels on the carbon balance are duly accounted for is one way to avoid the emergence of undesirable path dependencies. Developing metrics of value-creation per unit of feedstock may be another.

The policy debate has shifted from a focus on the energy sector, towards an economy wide transition in recent years. The emerging bioeconomy discourse broadens to transitions from an economy based on fossil fuels and fossil petrochemical feedstocks, to a more resource-efficient system based on renewable raw materials, produced through a sustainable use of ecosystem services from land and water (cf. Formas 2012).

6.7.2 Regime destabilising policies

The impact of the regulation on energy and environment is driving major change across industries and opening possibilities for biorefineries as it *destabilizes (D2)* the use of fossil energy and feedstocks. Policy impacts may exceed those of the market changes, including the impacts of ICT upon paper consumption and growth of the supply side competition in South America and Asia (Karltorp and Sandén 2012). While there are no policies deliberately seeking to destabilize the current product range of the wood based industries, strong support for biofuels may have an indirect destabilizing effect on the existing uses of forest resources; if it diverts an increasing share of the harvested woody biomass into fuel products.

6.7.3 Policy challenges and options

- An important challenge for policymakers is to avoid strong policy signals that lead to the use of forest-derived resources as fuels at the expense of potentially more valuable biorefinery products. Ensuring that the impacts of forest based fuels on the carbon balance are duly accounted for is one way to avoid undesirable path dependencies. Developing metrics of value-creation per unit of feedstock may be another.
- Circularity in biorefineries is related to a balance in the product range with a maximum share of high value products that can be circulated as products or material. Policy support for biofuels needs to ensure focus on high-grade fuels for transport modes that cannot readily switch to electricity (such as heavy goods, sea, and air transport).

Table 22. Policy landscape around the biorefinery innovation system in Finland and Sweden based on the TIS functions (C=creative, niche support functions; D=Destruction, regime destabilisation functions).

Finland	**Sweden**
Knowledge development and diffusion (C1)	
Long tradition of publicly funded research on both chemical and biotechnical utilization of biomass. Continuous flow of Tekes funding to technology programs from the 1980's to the present day in bioenergy area. Recent examples BioRefine-program (on biorefineries) in 2007-2012, the BEST programme (Sustainable Bioenergy for Tomorrow) 2013-2016	Substantial funding for research on liquid biofuels and gasification. Uncertainties regarding share of public funding: several funding agents, opportunities for private actors to perform own experimentation.
Establishing market niches/market formation (C2)	
Public procurement guidelines emphasize innovation and sustainability. Some public transport organisers prefer biofuels. Strong policy support for the creation of the market for biofuels and the respective industries have effectively scaled up the production.	Varying support and tax regimes for bio-fuels and bio mass (e.g. procurement, green certificates and carbon tax). No explicit policies for other bio-based materials from bio-refinery. Some regions purchases bio based products but not necessarily based on domestic content. Current preliminary proposals to make more use of public procurement from Tillväxtanalys. In some projects, actors from several sectors are included in order to promote a product chain perspective, and enable scaling up. Some market actors desire bio-based alternatives to fossil materials, however not necessarily sourced from forests.
Price-performance improvements (C3)	
No such policies detected	Applicable evidence not found in cases
Entrepreneurial experimentation (C4)	
VTT Bioruukki, a piloting centre for bioeconomy initiatives founded in 2015 with a 5 M€ support from the Government's five strategic priorities under the Key project 2: wood on the move and new products from forests.[30]	Very significant funding for pilot and testing facilities, related to biofuels and gasification processes; support at lower levels for bio based substances for other purposes. (examples: Processum, B4E) Support for entrepreneurial experimentation and some initiatives for product diversification. However, mainly not for conversion of established (or new) pulp mills. Efforts are not coordinated. Limited diffusion initiatives. A limited number of actors participate in several projects.
Resource mobilisation (C5)	
Tekes programme on cleantech and bioeconomy (Smart and clean growth) 2016- 2018.	Most initiatives aimed at biofuels. Lack of model for ameliorating first mover risk including actors of non-forest industry value chains
Support from powerful groups/legitimation (C6)	
Bioeconomy strategy and Government Programme. Pulp and biofuel actors actively promote bioeconomy. The national Energy and Climate Strategy 2016 emphasises strongly biobased solutions.	Most initiatives devoted to bioenergy, rather than green chemistry. Legitimacy not a major concern but weak/insufficient advocacy policies and apparently limited broader stake-

[30] Action plan for the implementation of the key project and reforms defined in the Strategic Government Programme, Government Publications 1/2016

	holder awareness of bioeconomy experimentation. Lack over overall vision, though the Swedish government has initiated a collaborative process at the national level devoted to a 'Circular and bio based economy'
Influence on the direction of search (C7)	
Bioeconomy strategy 2014 and Strategic Programme of the Sipilä Government 2015.	A number of Swedish national calls for projects and current ongoing research spread across a number of policy spheres (energy, innovation, forestry, and agriculture); apparently centering around Swedish Research and Innovation Strategy for a Bio-based Economy (Formas 2012). While lacking synchronisation and coordination, the intent to develop a harmonising circular- and bio-economy strategy has been gazetted.
New Control policies (D1)	
Mainly in the area of biofuels. The national energy and climate strategy flags aim to reduce the use of fossil oil by 50 %. The mixing obligation of biocomponents in liquid fuels represents a strong control policy (Act 446/2007).	Most policies have related to bio fuels (oil dependence in transport sector). REACH an indirect driver for bio based materials and/or chemicals, but provides limited incentives for the bio economy per se.
Significant changes in regime rules (D2)	
Mainly in the area of biofuels: Ethanol content of standard petrol increased to 10 %. Specific efforts to streamline permitting procedures for the Äänekoski biorefinery to support the strategic investment.[31]	Energy policies and energy price changes has changed the conditions for bio refineries for fuels. This shift many lead to differentiation and utilization of for instance the lignin fraction for other purposes.
Reduced support for dominant regime technologies (D3)	
None	None
Changes in social networks, replacement of key actors (D4)	
Biorefinery projects are mainly run by large incumbents in either pulping or energy. Producers of low volume, high value-added products are mainly new entrants, but they are still loose and scattered.	Improving the value added of various wood components is studied in several Finnish research programmes. These large consortia serve as platforms for new network development, but networks still apparently loose and scattered. Innovation networks growing and broadening beyond universities, forest industry actors, and fuel/energy companies (where biofuels were a central). Growing evidence that research institutes involved in materials and chemicals now taking a larger role, with hubs of activity forming around chemicals/materials organisations.

6.8 Concluding remarks

This study has compiled significant evidence that biorefineries offer many possibilities to further value-add woody biomass, an abundant and economically vital raw material for both Finland and Sweden. They also offer outstanding opportunities to leverage world-leading knowhow in both countries from within wood-based value chains and their technologies. As for the Nordic forest industries in general, biorefineries continue to offer opportunities for rural development and job creation (Teräs 2015) as they are expected to be located in relatively remote and sparsely populated areas in proximity to raw material feedstocks. This facet that aligns well with policy aims to maintain rural economies and quality of life. Further, the well-developed infrastructure of the incumbent forest sector industries in Sweden and Finland make the collection and processing of disperse, remote biomass much less of a barrier to a bioe-

[31] Samarbetsgruppen, Elina Linnove 2015. Kokemuksia Metsä FibreOy:n Äänekosken Biotuotetehtaan viranomaisprosessien sujuvoittamisesta (Erfarenheter av arbetet med att främja smidiga myndighetsprocesser för Metsä Fibre Oy:s bioproduktfabrik i Äänekoski)(In Finnish, Swedish abstract. Miljöministeriets rapporter 21 2015.

conomy transition than it may be for other countries or industrial contexts (Formas 2012). A summary of the differences and similarities of Finland and Sweden is presented in Table 23.

Table 23. Comparison of the biorefineries sectors of Finland and Sweden.

	Finland	**Sweden**
Actors	Major operators include incumbent pulp and paper or energy/fuel companies.	A few incumbents active in transformation towards biorefineries. Universities and traditional industries main actors (Pulp and paper, energy/fuel companies). Research institutes becoming more central (>2012)
Processes of commercial scale operations	Kraft pulp modifications for energy and lignin. Biofuel production using hydration, hydrolysis and fermentation.	Domsjö sulphite mill as a basis for multiproduct biorefinery. Kraft pulp modifications for textile pulp, speciality pulp, energy and lignin. Biofuel production using hydration, hydrolysis, fermentation and gasification pathways.
Products	Biofuels and kraft lignin dominate. Start-ups for value-added products are separate from biorefineries.	Biofuels, sulphite lignin, synthetic biomethane, emerging start-ups for value-added products and supporting processes.
Stage of commercialization	Many commercial operations of extended pulp mills and biofuel plants and several in planning stage.	Commercial operations in extended pulping and biofuels. Several failed commercialization projects in advanced biofuels.
Research and development	Few pilots, fundamental research at universities.	Several pilot scale, fundamental research on wood chemistry in public-private partnerships.
R&D funding	Tekes dominates	Dispersed funding, lack of coordination, hubs of research activity may be shifting towards State financed research institutes
Policy	Strong and stable support to biofuels through distribution mandate and taxation.	Uncertainties in biofuels strategy and taxation. Absence of mandate structure has constrained industry.

In a recent Swedish analysis, Palgan (2016) holds that at present, conflicts and contradictions appear to exist across bioeconomy policy domains where multiple funding agencies contribute. Even if the Swedish Government has stressed that their strategy should address multiple components, no clear coordinating structure was found for the many governmental funding bodies active in the sphere in this research. These bodies include *inter alia*: the Swedish Research Council (Formas), the Swedish Foundation for Strategic Environmental Research (MISTRA), a new ‘Innovation in the Forest Industries Programme’; the Swedish Innovation Agency Vinnova, and the Swedish Energy Agency. In Finland the activities are more coordinated because the government strategy on bioeconomy is very strong and the role of Tekes in funding of applied research especially in the area of bioeconomy is decisive.

As a complicating factor, this work highlights that the utilisation of biomass as a prime energy source in both Finland and Sweden threatens to outcompete both a number of promising chemical industry applications, and material applications of wood biomass and cause conflict within interest groups on the usefulness of the biorefinery concept in general. Therefore, care will be needed when designing future support for different parts of the bioeconomy, if progress towards value-adding and circularity is to be achieved, whilst also pursuing other social goals of importance such as climate mitigation. While the general approaches on biomass energy are similar in Finland and Sweden, the support of transport biofuel innovation appears stronger in Finland than in Sweden.

Circular bioeconomies require new types of R&D consortia combining actors from various parts of the value chain. Also consortia consisting of large and small actors for utilisation of various biorefinery side streams will need support if such opportunities are to be leveraged. Combining large and small material flows is challenging. One role of biorefineries in a circular economy could be the utilisation of by-products and waste materials. However regulatory barriers for using waste materials clearly exist and will need to be substantially reduced if by-product streams are to be fully utilised.

Photo: Plugi

7 Circular bioeconomy in the Netherlands

This section summarises recent developments of bioeconomy and circular economy solutions and governance in the Netherlands. The Section draws from a previous work benchmarking the Finnish bioeconomy against the Dutch, carried out by the Dutch Research Institute for Transitions (DRIFT), used as a starting point and further developed in this project. Earlier, the results and discussions have been presented by Bosman & Rotmans (2014, 2016).

The Dutch economy has notable differences to the Finnish and Swedish economies. The Netherlands is the sixth-largest economy in the euro-zone. Its industrial activity is concentrated around food processing, chemicals, petroleum refining and electrical machinery. The highly mechanised agricultural sector employs 2% of the labour force but provides large surpluses for the food-processing industry and for exports. The Netherlands hold huge investments in fossil economy, which characterises the country's current position in bio- and circular economy; but the country has the ambitious aim of being amongst leading countries in bio- and circular economy by 2050. For this, the country is well-positioned, with well-educated population. Large harbours and strong transport and logistics sector make it possible to import and transport biomass and bioproducts efficiently across the globe, also enabling the country serve as a logistical node for circular economy materials and products. The strong and well-advanced chemical industry is increasingly looking towards biobased, instead of petroleum-based, input in order to hedge against rising fossil fuel prices. Highly developed agro- and food and strong energy domain are other competences of the country. As compared to Finland and Sweden the situation with respect to the bioeconomy is very different. The Netherlands does not have huge biomass potential. In particular, it has no forestry biomass; the only potential available domestically is agricultural biomass, meaning that a large share of biomass will need to be imported.

The *Dutch Businessplan Biobased Economy* aims for The Netherlands to be amongst the top countries involved in the bioeconomy by 2050 and emphasises that: "A highly developed [bioeconomy] uses green resources firstly in the production of food and feed and only afterwards (or simultaneously in the case of waste products) for chemicals, materials and energy" (Werkgroep Businessplan Bioeconomy 2011). The Businessplan brings together the six key sectors—chemicals, agro-food, horticulture and raw materials, logistics, energy and water—to combine their efforts to further shape the leading role of the Netherlands in the transition to a sustainable society. By 2040, 40% of the resources used should be green, and by 2030 one out of three technical students should work in the bioeconomy, with CO_2-emissions cut 11.6 Mton and energy use reduced by 171 PJ.

The Ministry of Economic Affairs has a leading role in the biobased transition together with the chemistry sector, while the other sectors such as the energy, transport and agro-food still are more conservative and fossil-fuel dominated. The industries are balancing between their vested interests, on the one hand promoting the bioeconomy, and on the other hand protecting their own position and focussing on incremental innovation rather than radical innovation. At the moment, the Dutch bioeconomy is largely dominated by bio-energy as opposed to high-level specialised bioproducts, although examples of the latter are available. The transition to a Dutch bioeconomy was determined to be in the pre-development phase; it is growing fast but is still fragile, and there is a need for more biobased projects that could be scaled up relatively soon.

The Dutch bioeconomy strategy is based on network development and co-creation, combining a top-down and bottom-up approach, and using the principles of transition management. The aim is to bring diverse parties with various interests together, and to actively work on co-creation with these partners, and to strive for excellence and ambition (high up in the biomass pyramid), stimulating regional clusters. Searching, learning and experimenting are key elements of the process, as well as creating new networks that together could innovate new solutions, and successfully experiment them. The Dutch government has a facilitating rather than a directing role, e.g., facilitating the development of regional clusters with their own specific strengths in the bioeconomy, and the mapping of barriers to the bioeconomy, classified as operational, structural and fundamental.

In addition to the biobased economy, the Dutch government has recently been active on the circular economy front, and a government-wide programme called “A circular economy in the Netherlands by 2050” was launched in September 2016 (The Ministry of Infrastructure et al. 2016). Its vision is a future-proof, sustainable economy and a liveable earth for future generations, requiring the efficient use and recycling of raw materials as well as sourcing them in sustainable manner. It also necessitates fewer raw materials due to more efficient products and services, thereby helping to reduce the pressures on the living environment and public health. The programme aims at a completely circular Dutch economy by 2050. The first milestone, in 2030, is a 50% reduction in the use of raw materials such as minerals, fossil-based fuels and metals. Five chains and sectors have been given priority in the transition: biomass and food, plastics, manufacturing, construction and consumer goods. To accelerate the transition to a circular economy, the Dutch government plans to draw up ‘transition agendas’ in these areas, so that by 2050 they will only be using sustainably produced, renewable or generally available raw materials and be generating as little residual waste as possible. To support the high-quality recycling of products, smart return and collection systems are planned. A national raw materials agreement will be concluded with societal partners including the business community, government authorities and NGOs. Additionally, 27 million euros will be earmarked for improved waste separation and to fund new innovations aimed at improving the recycling capability of products.

A key finding of the comparison between the Netherlands, Finland and Sweden is the fundamental difference in the focus of innovation efforts within product lifecycles (Table 24). Dutch bioeconomy developments tend to be product oriented whereas Finland and Sweden have placed key emphasis on production and extraction of domestic raw materials. Due to natural reasons, in the Netherlands, agro-based biomass is the main raw material, while in Finland and Sweden focus in on forest-based biomass and their side streams. The precipitator of the Dutch bioeconomy lies in the chemical sector. Thus, when compared to Finland and Sweden, the main interest of Dutch industries’ can be seen to be more in the upper part of the biomass value pyramid, meaning such as pharmaceuticals, fine chemicals, as well as food, feed and nutrition. Some Dutch company examples in textiles, construction and biorefineries supporting transition towards circular bioeconomy are presented in Table 25. So far, most of these concepts are still conceptual or niche activities, but have significant potential in renewing international value chains and business ecosystems. Currently, all three countries share the same challenge of aligning innovative biobased circular economy elements into a large-scale transition of value chains and business ecosystems.

Table 24. A comparison of ideas and drivers in the Dutch and the Finnish (largely also applicable to Sweden) approaches to bioeconomy transitions in 2014 (from Bosman and Rotmans 2016).

	Dutch Biobased Economy	Finnish Bioeconomy
Transition	Fossil to biobased	Bulk to specialty
Drivers	Chemistry sector/government	Bioeconomy and innovation in genes
Urgency	Rather high	Average
Phase	Pre-development	Just before take-off
Regime	Economic top sectors	Powerful silo structure
Niches	Systematic experimentation	Many unconnected pilots
Vision	Co-created vision for 2050	Government-led vision for 2025
Governance	Transition governance	Traditional top-down
Scale	Regional	National
Approach	Conceptual, network-based	Practical, sector based
Focus	Radical innovation	Incremental innovation
Government	Facilitator	Director

Table 25. Examples of some companies and initiatives supporting the renewal of manufacturing towards circular bioeconomy in the Netherlands.

Name	Aspects on the renewal of manufacturing towards circular bioeconomy	Type
Textiles		
Interface	Reuse of old fish nets to make floortiles	Large
Dutchspirit	Recyclable textile for work clothing	SME
MUD Jeans	Leasable and reusable jeans	Start-up
Creative City Lab	Reuse of wool textiles	Start-up
Van Hulley	Boxershorts out of old shirts	SME
Waste2Wear / Vision Textiles	Uniforms out of recycled PET-bottles	Large
G-Star Raw	Jeans out of plastic soup	Large
LENA Fashion Library	Library to borrow clothing	Start-up
Dutch aWEARness	Recycling workwear	Start-up
Construction		
KWS Infra	Developed the plastic road, based on recycled PET and plastic soup	Large
Sustainer Homes	Holiday cottages in sea containers with 3D printed and recycled furniture	Start-up
C2C Expolab	Reusing and developing healthy building material	SME
City of Utrecht	Reuse of old roof of central station for market	City
Cirkelstad	Circular design and maintenance of buildings and reuse of construction material	Platform
Thomas Rau	Circular design and construction	SME
Biorefineries		
Van Houtum	Recycling waste paper and cardboard to make toilet paper	SME
Peeze	Biobased and compostable coffee cups for Nespresso machine, filled with climate neutral fair trade Peeze coffee	SME
PEP Business Creators BV	Organic production and use of biodegradable plastic pots	SME
SITA	Plastics, paint, and other chemicals	Large
Avebe	Partner in Dutch Biorefinery Cluster, refining potato proteins and starch	Large
Friesland Campina	Partner in Dutch Biorefinery Cluster	Large
GRASSA BV	Biorefining of grass into feed and fibres for paper	Start-up
Bio Energy Management	Recycling and (bio)waste separation	SME
Cargill Refined Oils Europe	Refining of vegetable oils and fats for food industry	Large
ChainCraft	Upcycling of waste	Start-up
Neste Oil	Refining waste products into biofuels	Large
Suikerunie / COSUN	Sugar as input for food and chemicals	SME

Corbion	Lactic acid as input for food products, biochemicals, bioplastics and biopharmaceuticals	Large
AkzoNobel, Basidiofactory, Bioprocess Pilot Facility, ChainCraft, Delft Advanced Biorenewables (DAB), Friesland Campina, MicCell Bioservices, Microdish, Microlife Solutions, NIZO food research, B.V., SkyNRG	Involved in BE-basic public private partnership to develop industrial biobased solutions to build a sustainable society	Including variety of large firms, SMEs and start-ups
DSM	Involved in many circular bioeconomy initiatives in areas such as health, food, chemicals, textile and construction	Large
Heineken Supply Chain	Involved in several circular biobased economy pilots, where they source their products locally and close material loops	Large
Photanol	Technology converting CO_2 into organic compounds	Start-up
GasUnie	Part of the Green Goods Farm green deal, working towards fermenting syngas as biobased feedstock for the chemical industry	Large

Photo: Image bank of the Environmental Administration/ Aarno Torvinen

8 Synthesis - Where are Finland and Sweden standing in regard to circular bioeconomy?

The purpose of RECIBI was to deepen understanding of the opportunities, barriers, impacts and policy implications of a circular bioeconomy by examining very different situations for the renewal of manufacturing. In this synthesis, we summarise the main findings of three case sectors—textiles, multi-storey wood construction and biorefineries—using wood as raw material.

The backdrop and motivation for this study was the ongoing transformation of the forest-based industries, which cannot count on product increasing demand for growth, e.g. printing paper. Therefore, many actors are looking into new business areas where the demand is growing such as wood-derived textiles, packaging materials and biofuels. The renewal of forest based industries is, however, not a simple solution developing new products and identifying markets. The strong focus on the needs to decarbonize the economy and increase resource efficiency has become an important additional driver for industry renewal.

The bioeconomy, and especially the increased utilisation of wood for novel products and energy, are expected to provide opportunities for Finland and Sweden. The rate of renewal of forest resources is, however, finite. This necessitates the consideration of how to best maximise the added value and make use of virgin raw materials. This is the essence of the circular economy. So far, the discussions and activities related to the promotion of the bio and circular economies have been largely separate efforts. However, there are signs that these two discussions may converge. In efforts to renew wood based manufacturing the two angles should be dealt with simultaneously.

The Finnish and Swedish pulp and paper sectors have been frontrunners in areas such as resource efficiency, recycling and bioenergy. Therefore further improvement of resource efficiency and waste reduction, coupled with new products, services and business models are likely to offer new opportunities to the sector. These business models may require radical changes in the design of products and services in order to fulfil the principles of a circular bioeconomy.

To contribute to the renewal of forest-based industries the RECIBI project extensively reviewed recent literature and documents. The desk studies were supported by interviews with experts and practitioners in the case sectors. Theories of socio-technical transitions provided the overall frame for examining the renewal of manufacturing, with particular reference to the multi-level perspective (MLP) and technological innovation systems (TIS). Environmental aspects were assessed based on life cycle thinking. For the Finnish textile sector, the macroeconomic remanufacturing potential was examined using environmentally extended long-term input-output projections using the ENVIMATscen-model.

A key question in this study is how policy can support and steer industry renewal. During this work, four policy briefs were produced (Hildén et al. 2016a, 2016b; Judl et al. 2016; Kautto et al. 2017) highlighting the role of the public sector in industry renewal. The following sections highlight the key issues and also compare the conditions for renewal in Finland and Sweden.

8.1 The growing textile sector needs a circular bioeconomy to solve raw material and waste problems

The global demand for textile fibres is continuously growing due to increasing standards of living and short use times of clothing and household textiles. The demand for wood-based textile fibres is expected to grow mainly because of stagnating cotton production, but also because of emerging signs that synthetic fibres, which currently dominate the market, may come less acceptable. The traditional wood-based fibre production process (i.e. viscose) is, however, environmentally harmful and not necessarily less harmful than cotton production. Therefore the future potential of wood-based textile fibres lies in the so called novel viscose processes. There is intense R&D on the topic in both countries. Promising production processes have reached demonstration stage, notably the Finnish Ioncell F, yet there are still hurdles on the way to commercial production.

Currently, in Finland and Sweden, most textile waste ends up in municipal solid waste streams that result in incineration. Reuse and recycling have traditionally been organised by charities, although small-scale actors developing novel business models for reuse, repair and utilisation of waste materials are emerging as niche markets. However, these flows are still very small compared to the volumes going to waste collection. A challenge for developing circularity of materials in the textiles sector is that many of the supply chains related to textile production are global, long and complex. Circularity on a larger scale therefore requires extended producer responsibility (EPR) approaches and take back schemes similar to those of, for example, batteries and electrical appliances, combined with incentives to develop the reuse of textiles and not only fibres. Simultaneously, all national-level extended producer responsibility systems are challenged by the increase in online shopping.

While Finland actively advances so called novel viscose production technologies, in Sweden focus is placed on increasingly diverse value chains and recycling activities. In addition, Swedish based global actors in fashion and home textiles have ambitious targets for more sustainable and recycled textile fibres.

A key challenge in developing a circular economy for (wood based) textiles is to overcome the gap between the search for novel processes for cellulose-based fibres and the exploration of new possibilities for the recycling of textiles. Broad cooperation of actors is needed to overcome current bottlenecks in the design and implementation of circular business models. In both Finland and Sweden, several initiatives have recently emerged in which broad consortia seek solutions for promoting textiles in the circular bioeconomy. Scenario modelling for Finland performed for the year 2030 indicates positive overall economic and employment impacts if clothes are worn longer and or if more viscose production occurs. On the other hand, whilst environmental impacts would increase in Finland, greenhouse gas intensity would decrease and resource efficiency would improve due to advanced technologies.

In both counties, apart from R&D funding contributing to knowledge creation and influencing the direction of search, few policies explicitly support growth and circular material flows in the emerging wood-based fibres subsector. Currently signs of changing design and consumption patterns are still insignificant, even though decarbonisation may eventually reduce the legitimacy of fossil based fibres and textiles. Some differences were identified in the practices and interpretation of policies and legislation between Finland and Sweden. For instance expected EPR system for textiles has encouraged more small scale entrepreneurial experimentation with collection and recycling in Sweden. Policies, such as the revised acts on public procurement that have been adopted in both countries, may strengthen the opportunities to commercialise wood-based and recycled fibres, thereby supporting market formation. In Sweden, a reduced VAT for repairs was also recently introduced, giving impetus to seek opportunities to re-use textiles. In Finland, the ban on landfilling of organic waste could in principle enhance circularity, but at present most textile waste is incinerated. Additional policies are needed to reduce this 'textile leakage' and to encourage recycling; for example a tax on waste incineration could have such effects.

8.2 Multi-storey wood construction requires learning and leadership

Wood construction is one of the showcases of the bioeconomy, but despite numerous efforts the market share of wood in multi-storey buildings remains low. In recent years, innovations in wood material and construction technologies, renewed fire-safety regulations and numerous government programmes should enable broader use of wood in multi-storey buildings, but the market has grown slowly. Given that multi-storey wood buildings were introduced in the mid-1990s, as well as the inherent conservatism and complexity of the sector, the current market shares in Finland and Sweden may reflect reasonable expectations.

The construction sector differs greatly from the textile sector, the main difference being the lifespan of the products; buildings have long life-times and thus require appropriate maintenance and repair. The long lifetime and strong liabilities also lead to cautious attitudes within the sector. There is a very strong "concrete regime" that is maintained by strong incumbents, adopted practices, existing skills and education focus.

There is a clear difference in the market shares of multi-storey wood buildings in Finland and Sweden. In Finland, the market share is 6%, compared to approximately 10% in Sweden. In Finland, multi-storey wood building projects have been scattered and isolated both in terms of locations and actors, which has prevented effective niche learning and limited price performance improvement, resulting in unattractive costs for both builders and users. In Sweden, a number of municipalities and producers have taken the lead and advocated multi-storey wood buildings. The initial factual challenges, such as acoustics, energy efficiency, quality assurance in production, have essentially been resolved.

Industrialised building production through prefabricated modules and elements is a promising path for increased capacity and cost reductions while also incorporating aspects of the circular bioeconomy. There is a joint interest from both business development and circular bioeconomy perspectives to further the growth of industrialised building production since there is an ample potential for advancing circularity aspects in business models; for instance, through construction that allows flexible use of buildings.

Due to the long life time of buildings, the main opportunities in line with the circular economy lie in the possibilities for refurbishing and remodelling of existing building sock with light-weight wood elements and components. The demolition and reuse of materials and elements in wood buildings has also been discussed lately. So far, circular economy aspects have largely been neglected when it comes to wood construction. Improved design of building materials, as well as the avoidance of substances or structures that prevent end-of-life reuse or recycling, are also important for circularity. Therefore, innovations in the field of components and composites that address the recovery and recycling challenges improve possibilities to establish a circular economy.

Export is a poorly tapped potential for wood building structural components and prefabricated modular solutions. Here additional challenges comprise, among other things, customisation, understanding of selected markets and their specific standardised quality requirements. This is an undertaking that requires additional capacity building and experimentation. In addition to the prevailing market challenges, there is also logistical challenges that need to be addressed.

Currently, we notice increasing volumes in multi-storey wood buildings, expanding production capacities in manufacturing plants and raised interest among actors in the sector. Particularly in Sweden, wood buildings have been included in public procurement agreements and real estate companies perceive lower building costs when using prefabricated and industrially produced buildings from wood. Thus, we see preparedness and capacity to lead to a radical increase in volumes.

8.3 Biorefineries need to aim for high value added products

The case on biorefineries differs very much from the cases above, as it does not present a group of products serving a specific function but rather a type of process or factory. Biorefineries are analogous to oil refineries in processing raw material into a number of products minimizing low-value fractions. They represent the idea of the bioeconomy that replaces fossil raw materials with renewable feed stock.

Most biorefineries of today can be characterized as either extended pulp mills in which additional wood components are turned into products, or biofuel units where wood or some wood components are turned into fuels. Examples of biorefineries are Domsjö Fabriker in Sweden and the new bioproduct mill which is under construction in Metsä Fibre Äänekoski mills in Finland. Domsjö Fabriker produces a broader scale of marketable products than other Finnish or Swedish pulp mills and Äänekoski mills are in the process of developing partnerships with other companies for a broader utilization of both larger and smaller fractions of the pulp process. Additionally, for example, the Sunila mill in Finland shows that markets are developing for the lignin fraction of wood, which so far has been only utilized for energy production at the mill.

The main challenge for Finnish and Swedish biorefineries is that most of the products are still in the low end of the value added pyramid. They fit the existing business logic of large scale manufacturing and do not renew it. A strong emphasis on bioenergy and biofuels production has characterized current discourse on biorefineries. It is problematic in at least three ways. First, the feedstock supply is limited for the vast energy needs leading potentially to competition for raw-material. This benefits forest owners, but decreases competitiveness of export products. Second, the value-added in biomass-fuel production chains is rather low. Third, it may turn out to be a technological lock-in that stifles the development of more innovative uses of forest resources.

In both Finland and Sweden there is a long tradition of R&D support to various technologies for utilization of biomass and development of biorefineries, but policies and funding instruments have been heavily biased towards enhancing development and use of biofuels. For example the distribution mandate aiming at increasing the total share of biobased fuels in the energy mix is a strong measure for market formation. The Finnish targets even exceed the EU targets. In addition the policies that disrupt the existing regime mainly focus on paving the way for biofuels at the expense of fossil fuels.

8.4 There are more similarities than differences between Finland and Sweden

The three cases—textile sector, multi-storey wood construction and biorefineries—show the differences in a renewal of manufacturing towards a bioeconomy, a circular economy and a circular bioeconomy (Table 26).

Table 26. The objectives and needs for renewal of manufacturing towards a bioeconomy, a circular economy and a circular bioeconomy and the current state of play in Finland and Sweden.

Bioeconomy	Circular economy	Circular bioeconomy	Finland	Sweden
Textile sector				
Active response to anticipated growing demand for textiles. Replacement of synthetic fibres with wood-based fibres	Develop collection systems and demands Extend life time through design Reuse textiles Recycle fibres	Support R&D for new wood based products and processes, including treatment of recovered raw materials. Piloting collection systems and ecosystems of use. Support commercialization of wood based fibres. Focus on design and fashion to extend use time Create incentives for new networks for recycling and for linking with spinning and weaving that takes place abroad	Active R&D work to develop novel wood-based fibres for textiles. Business models for collection and processing of used textiles are still on a very small scale	Prioritised policy focus for CE supported by large global textile industry actors: emerging new collection schemes; new business concepts and some incentives for lease, rent and repair

Bioeconomy	Circular economy	Circular bioeconomy	Finland	Sweden
Multi-storey wood construction				
Replacement of steel, concrete structural elements. Use of wood building as carbon storage	Increasing emphasis on maintenance and modifications to extend life time; Emphasis on material reuse in demolition through prefabricated elements and modules.	Need to significantly expand the number of pilot high-rise buildings for dissemination of knowledge and experiences. More transfer of know-how from small buildings. Need to demonstrate advantages of wood for users (environmental performance, user properties). Critical need to overcome path dependence determined by existing capabilities. Important to focus on maintenance and other long life time challenges to circularity that have so far largely been neglected.	Systematic promotion of wood construction on national scale, but the construction sector still dominated by a ‘concrete paradigm.’ Shadow effect of fire safety regulation and the concrete based building for rapid urbanisation. Wood construction projects have so far been separate efforts, but recent signs in increasing activities in multi-storey wood construction.	Concrete paradigm dominant. National strategy for wood buildings (2004) supported by local government strategies and activities. Current network of wood building cities. Public procurement has a role in forming markets. Markets developing faster than in Finland; may be partially explained by faster growth of the building sector. Non-incumbent SMEs lead technical and manufactural development. Aiming for industrialised production and construction.
Biorefineries				
Replacement of oil-based chemicals or fossil fuels. Increase of value added from wood.	Internal process-recycling, expansion of recycling systems based on end products	Increased focus on product and technology development in e.g. lignin use and base chemicals production. Need to avoid too strong emphasis on high volume but relatively low value products such as fuels.	Biorefineries dominates the bioeconomy discussion. Strong and stable support to biofuels in strategies through distribution mandate and taxation. Major operators are incumbent pulp and paper or energy/fuel companies.	Several pilot scale, fundamental research on wood chemistry in public-private partnerships. Uncertainties in biofuels strategy and taxation. Limited interaction between forest and chemical industry for market development.

Both Finland and Sweden are still a long way from achieving a renewal of the forest based industries that would contribute to a rapid societal progress towards a full blown circular bioeconomy and a complete transition away from the dependency on fossil fuels and fossil raw materials. Currently the bioeconomy is a partial solution that has helped to raise the proportion of renewables in the energy mix in Finland and Sweden, but it faces constraints in the form of, for example, diminishing carbon sinks that otherwise would maintain ‘negative emissions’.

The Finnish discussion on manufacturing renewal puts great faith in the bioeconomy and utilization of forests as a raw-material, although, for example, the official bioeconomy strategy also recognizes ecosystem values and intangible use of biomass. The mapping of current biorefinery projects performed in this study shows increasing pressure to use forest biomass, even reaching the maximum sustainable harvest. In Sweden, the hopes pinned on the bioeconomy are less dominant. Consequently Sweden's decarbonisation policy is, for example, based on a greater variety of renewable electricity options than Finland's. This can partly be understood based on differences in natural endowments between the countries, but it also demonstrates the strength of industrial path dependence.

To take full advantage of the potential sustainability benefits of a renewal of manufacturing towards a circular bioeconomy, sustainable land-use needs to be factored in by recognising biomass supply constraints and requirements posed by a wide range of ecosystem services, including maintenance of carbon sinks and biodiversity. To do so, activities promoting the bioeconomy and circular economy need to be brought closer together. An integration of the concepts under a circular bioeconomy (Table 26, middle column) would provide many potential benefits for the renewal of manufacturing, including new businesses and innovations.

A renewal of manufacturing towards a circular bioeconomy could support regional and rural development and also improve the state of the environment through increasing demands on, for example, the maintenance of forest and other biomass values, and the creation of markets for products, by-products and residuals. Ideally ecosystem services and a reduction of emissions of greenhouse gases and pollutants become complementary co-benefits.

There is a consensus in industrial and innovation policy that success in renewal of manufacturing is more likely with an emphasis on high value added per unit of (extracted) biomass. Many actors in the Nordic forest based industries recognize the imperative to find ways of developing a more sophisticated portfolio of specialized products and a diverse bio-economy instead of depending on a few bulk products. The transition towards a circular bioeconomy will require still more development and deployment of innovative business models and cross-sectorial collaboration, which take into account the value pyramid or cascading use of biomass.

The current economy is still heavily dependent on fossil and other non-renewable material cycles, and a destabilization of those is needed, for example in the form of significantly increased costs of the use of fossil fuels and raw materials, to support emergence of biogenic supply chains. But this will not be enough. The transition towards a circular bioeconomy also requires design for circularity. This implies RDI support and activities that focus on design for modularization, deconstruction and resource recovery, as well as new resource recovery/reuse/ recycle business models. The viability of the circular economy solutions should be assessed using life cycle thinking that can compare alternative processes, products and product systems. In addition, the viability of the circular bioeconomy is also dependent on strategic choices such as the role of renewable materials and fuels.

9 Conclusions and recommendations

General findings

Definitions of the bioeconomy in both Finland and Sweden emphasize the need for overall sustainability. However, sustainability from a life cycle perspective is not always easy to achieve in wood based products and processes. For example, the limited availability of raw materials, the use of energy and hazardous chemicals in production processes, toxic or fossil-based additives in products and poor waste management practices may make biomass-based products a source of severe environmental impacts. Additionally, choosing between the use of biomass as raw-material or its use to support many ecosystem services can create conflicts. As forerunners in sustainable practices, the interest of Finland and Sweden is to ensure that any renewal of manufacturing improves the sustainability of the whole bioeconomy. This will also benefit the industrial actors that need to find a competitive edge in the global markets.

The policies and practices for the bioeconomy and the circular economy are still loosely connected. A renewal towards a real circular bioeconomy is primarily hampered by two missing elements. Firstly, products are not designed for a circular economy. For example, they consist of multiple materials that are difficult to separate from each other or they contain toxic components. Secondly, the circular economy actors organizing material collection and recovery do not cooperate with the potential users of recovered materials. This has led to, for example, a lack of sorting and quality criteria that would create and maintain demand in the circulation of materials and products.

Differences and common strengths in Finland and Sweden

Circular and bioeconomy developments in the case areas (i.e. textiles, wood construction and biorefineries) are broadly similar in Finland and Sweden. However, there are some clear differences in national strengths, which could at best be combined to develop world leadership in the circular bioeconomy.

Finland is stronger in the development of novel textile fibres based on wood or recycled materials (e.g. Ioncell-F). In Sweden, greater textile volumes have allowed for experimentation in collection methods and new sorting capacity. Large Swedish customer brands such as H&M and IKEA also have the capacity to invest in significant collection schemes and have high ambitions to increase the use of novel and recycled textiles. By joining forces, consortia in Finland and Sweden could form collaborative innovation ecosystems that could significantly advance the circular bioeconomy in the case of textiles. A challenge is to provide globally competitive solutions for the highly international markets.

In multi-storey wood construction, Finland has emphasized national programmes for enhancing wood use, whereas Sweden has strengthened its focus on the local activities. In Finland, there are a number of scattered showcase high-rise wood buildings; whereas Sweden has a number of residential areas where high-rise wood buildings (e.g. Växjö) are becoming dominant. The market penetration of high-rise wood buildings is larger in Sweden, most likely because a critical mass for learning has been achieved. There is good potential in collaborative development of leadership in multi-storey wood construction using the possibilities of modular construction and industrialised production, which allows for improved material efficiency and better flexibility of buildings during their lifetime. By combining forces with the activities directed at, for example, nearly zero energy buildings, competitive wood buildings and wood building techniques that provide clear additional user benefits could be achieved.

The European and national policy landscapes have contributed to a strong emphasis on biofuels. Therefore, the average value added of biorefinery products is low in Finland and Sweden. The long tradition of research and development in wood chemistry provides, however, a great potential for both countries to develop novel high value added products using, for example, the hemicellulose and lignin fractions of wood. However, this will require more product oriented R&D. It is a slow process due to the simultaneous need to manage risks, actor alignment, finance large-scale production and safeguarding economic competitiveness.

Policy recommendations

Based on the RECIBI project, the following policy recommendations can be given to support the renewal of manufacturing in the wood based industries towards a circular bioeconomy:

- continue R&D funding for scientific and technical development as well as market preparation of textile fibres, modular wood construction and high value-added wood-based products,
- ensure that public R&D funding for a bioeconomy includes demands to evaluate the overall sustainability and circularity of proposed products, processes and services,
- make public R&D funding in the construction area conditional on the involvement of the users of buildings and the use of life cycle thinking in evaluating potential benefits,
- use special R&D funding to foster innovative product design for circularity,
- create incentives to form broad stakeholder consortia to ensure the emergence of functioning circular bioeconomy business models that include collection systems, remodeling and refurbishing as well as markets for the products being circulated,
- use public procurement to support market formation for novel circular bioeconomy solutions,
- pay greater attention to coherence across policy areas such as innovation, finance, taxation, transport, environment and product safety. For example, a tax reform to favour low resource use and reuse/repair should be investigated. Additionally, product safety regulations should ensure that the use of toxic materials in products does not prevent reuse or recycling.

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Appendix 1. Informants of the study

1A. List of interviews within the RECIBI-project

Case: Textile sector

Finland

1. Professor Ali Harlin, VTT, face-to-face interview, June 16, 2015.
2. Professor Herbert Sixta, Aalto University, face-to-face interview, September 3, 2015.
3. Päivi Talvenmaa, Tampere University of Technology, phone interview, August, 2015.
4. Marjo Blomberg and Anna-Kaisa Auvinen, Finnish Textile & Fashion, face-to-face interview, October 23, 2015.
5. Anna-Leena Teppo, Marimekko, face-to-face interview, October 27, 2015.
6. Erica Adlercreutz, Seppälä, face-to-face interview, December 12, 2015.
7. Elli Ojala, Finlayson, e-mail conversation, May 11, 2015.
8. Hanna-Maija Salonen, M.A.S.I. Company, phone conversation, December 12, 2015.
9. Senior researcher Helena Dahlbo, SYKE, face-to-face interview, May, 2015.
10. Timo Hämäläinen, Finnish Solid Waste Association, face-to-face interview, October 5, 2015.
11. Helena Käppi, Finnish Association for Textile Recovery, phone interview, May 11, 2016.
12. CEO Seija Lukkala, Globe Hope, face-to-face interview, September 29, 2015.
13. CEO Anniina Nurmi, Nurmi Clothing, face-to-face interview, n.a.

Sweden

1. Åsa Östlund, SP, personal conversation, Sept 7, 2016
2. Peter Axegård, Innventia, phone conversation, Nov.2, 2016
3. Jonas Aspling, Swerea/IVF, face-to-face interview, October 14, 2015
4. Tobias Köhnke, Swerea/IVF, face-to-face interview, October 14, 2015
5. Erik Perzon, Swerea/IVF, face-to-face interview, October 14, 2015
6. Lisa Schwarz, Swerea/IVF, face-to-face interview, October 14, 2015
7. Lars Winter, Domsjö Fabriker, phone interview, Dec. 2, 2015
8. Peter Lenhardt, Freudenberg, phone conversation, Dec 2, 2015
9. Urban Ohlsson, SKS, phone conversation, May 28, 2015
10. Louise Norlin, re:newcell, phone interview, Dec.14 2015
11. Charlotte Walse, IKEA, phone conversation, June 5, 2015
12. Eliina Brinkberg, Nudie Jeans, face-to-face conversation, May 10, 2016
13. Klaus Rosinski, ReturText, phone conversation, May 29, 2015

14. Magnus Fransson, Wargön Innovation, phone conversation, May 26, 2015 and Feb. 9, 2016
15. Eva Carlsson, Houdini, face-to-face conversation and presentation, Oct 12, 2016
16. Mårten Hellberg, OrganoClick, phone interview, Dec.12 2015
17. Cecilia Brännsten, H&M, phone interview, Dec.11 2015
18. Erik Karlsson, H&M phone interview, Dec.11 2015
19. Jon Nilsson-Djerf, Waste Management Sweden, phone conversation, Feb. 8 2016.
20. Anna Jiffer, Returtex, phone interview,
21. Lena Pripp-Koviac, IKEA, face-to-face interview, March 7, 2017
22. Anna Palmberg, IKEA, face-to-face conversation, March 7, 2017
23. Anne-Charlotte Feldt, IKEA, face-to-face conversation, March 7, 2017
24. Yvonne Augustsson, Naturvårdsverket, face-to-face conversation, Oct 12, 2016

Case: Multi-storey wood construction

Finland

1. CEO Mika Airaksela, Rakennusliike Reponen Oy, face-to-face interview, February 24, 2016
2. Building Counselor Harri Hakaste, Ministry of the Environment, face-to-face interview, May 9, 2016
3. VP Stakeholder Relations Timo Heikka, Stora Enso Oyj, face-to-face interview, December 12, 2015
4. Investment Manager Jan Hellman, IceCapital REAM, face-to-face interview, February 26, 2016
5. Professor Seppo Junnila, Aalto University, School of Engineering, Department of Built Environment, face-to-face interview, November 19, 2015
6. Director Esa Kosonen, Metsä Wood, face-to-face interview, collected earlier
7. CEO Heli Kotilainen, Green Building Council, face-to-face interview, February 24, 2016
8. Director Matti Kuronen, Bonava Oyj, face-to-face interview, March 20, 2017
9. VP R&D and Biomaterials Duncan Mayes, Stora Enso Oyj, face-to-face interview, December 12, 2015

Sweden

1. Ewa Magnusson, BoKlok, phone interview, Feb. 18, 2016
2. Peter Jacobsson, Martinson, phone interview, Feb. 17, 2016
3. Johan Gerklev, Skanska, face-to-face interview, Dec. 15, 2015
4. Sara Gorton, NCC, phone conversation, Feb. 18, 2016
5. Christina Claeson-Jonsson, R&D manager, Feb. 10 2016
6. Roger Persson, NCC, phone interview, Feb. 27, 2017
7. Lars Atterfors, Atterfors Consulting (former at Moelven), phone interview, Sept. 30, 2016

8. Anders Josephsson, Svenska Träbyggnadskansliet, phone interview, Feb. 18, 2016
9. Arne Olsson, Folkhem, phone interview, Feb. 15, 2016
10. Madelaine Hjortsberg, Boverket, phone conversation, Jan. 10, 2017
11. Mårten Hellberg, OrganoClick, phone interview, Dec.12 2015
12. Yvonne Identeg, Trä- och Möbelföretagen, phone conversation, Sept. 2, 2016
13. Gustav Edgren, Trä- och Möbelföretagen, phone conversation, Sept. 2, 2016
14. Hans Andrén, City of Växjö, phone conversation, Nov. 25, 2016
15. Marianne Hedberg, Sveriges Byggindustrier, phone interview, Feb. 11, 2016
16. Johnny Kellner, SBUF (construction industry's organisation for research and development), phone conversation, Sept. 12, 2016
17. Per Löfgren, JM, face-to-face conversation, Feb. 8, 2016
18. Per Wretlind, DTU, phone conversation, Nov. 27, 2015
19. Mikael Bergström, County Administrative Board of Västerbotten and Trästad, phone conversation, Nov. 25, 2016

Case: Biorefineries

Finland

1. Project Director Timo Merikallio, Metsä Fibre, face-to-face interview, September 7, 2015
2. Managing Director Tuomas Mustonen, Paptic, face-to-face conversation, April 26, 2016
3. VP Stakeholder relations Timo Heikka and VP R&D Duncan Meyes, Stora Enso, face-to-face interview, December 3, 2015
4. Managing Director Miikka Jokinen, Repolar, face-to-face conversation, October 22, 2015
5. Professor Herbert Sixta, Aalto University, School of Chemical technology, face-to-face interview, September 3, 2015
6. Research Professor Ali Harlin, VTT, face-to-face interview, June 16, 2015
7. Professor Emeritus Bjarne Holmbom, Åbo Akademi, face-to-face interview, April 14, 2011

Sweden

1. Gustav Tibblin, Södra, phone interview, July 5, 2016
2. Urban Blomster, Södra, phone interview Nov. 27 2015
3. Sune Wännström, SP, phone conversation, Dec 22, 2015
4. Lars Winter, Domsjö Fabriker, phone interview, Dec. 2, 2015
5. Nils Hannertz, Innovation and Chemical Industries, phone conversation, Jan. 5, 2016
6. Ola Wallberg, Department of Chemical Engineering, Faculty of Engineering, LTH, phone conversation, Feb 2, 20016

1B. Participants in the RECIBI-project stakeholder meetings

1. Stakeholder workshop 23 March 2015, Helsinki

Name	Organisation
Paula Kivimaa	SYKE
Riina Antikainen	SYKE
Petrus Kautto	SYKE
Tiina Jääskeläinen	SYKE
Armi Temmes	Aalto
Mika Kuisma	Aalto
Åke Thidell	IIIEE
Håkan Rodhe	IIIEE
Philip Peck	IIIEE
Jachym Judl	SYKE
Mikael Hildén	SYKE
Sirkka Koskela	SYKE
Rick Bosman	DRIFT, Netherlands
Markku Leskelä	FiBiC
Christopher Palmberg	Tekes
Heikki Aro	Tekes
Erja Ämmälahti	Tekes
Jyri Arponen	Sitra
Maija Pohjakallio	Kemianteollisuus

2. Stakeholder workshop 14.9.2016, Helsinki

Name	Organisation
Riina Antikainen	SYKE
Rick Bosman	Drift
Daniel Johansson	Vinnova
Jáchym Judl	SYKE
Pirjo Kaivos	CLIC Innovation
Petrus Kautto	SYKE
Mika Kuisma	Aalto University
David Lazarevic	SYKE
Michael Novotny	KTH Indek
Elli Ojala	Finlayson Oy
Christopher Palmberg	Tekes
Philip Peck	IIIEE at Lund University
Maija Pohjakallio	Kemianteollisuus ry
Sanna Pulkkinen	Finnish Forest Industries Federation
Håkan Rodhe	IIIEE at Lund University
Alina Ruonala-Lindgren	Finnish forest industries federation
Lennart Stenberg	Vinnova
Tero Stjernstoft	VINNOVA – Swedish Governmental Agency for Innovation Systems
Armi Temmes	Aalto University School of Business
Åke Thidell	IIIEE at Lund University
Anne Toppinen	UH
Erja Ämmälahti	Tekes

This report delivers new understanding of the potential of circular economy for sustainable renewal of manufacturing in bio-based industries. With particular focus on novel value chains, it provides novel insights into the role of innovation policies in facilitating the shift towards sustainable, circular bioeconomy in Finland and Sweden. The textile and multi-storey wood construction sectors, and emergent biorefineries are utilised as case studies that deepen understanding of the circular bioeconomy, its opportunities, barriers, and impacts, and the policies that affect its emergence.

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